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Alternative Fuels for Use in DoD / Army Tactical Ground Systems

ARC Collaborative Research Seminar Series – Winter 2011

Patsy A. Muzzell, Alternative Fuels Team Leader

4 February 2011

Report Documentation Page

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Standard Form 298 (Rev. 8-98)
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Disclaimer

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Outline

- TARDEC / NAC Overview
- The need to qualify alternatives to JP-8
  - Army Bulk Fuels Roadmap
  - The need to qualify
    - Tri-Services Energy Security Plans
    - Army Energy Security Implementation Strategy
    - TARDEC RDT&E supporting qualification of alternative fuels
    - Commercial vs. military diesel engine market
- JP-8 logistical fuel
  - What is JP-8?
  - What does it look like?
- Alternatives to JP-8
  - Terminology
  - What are the current alternatives to JP-8?
  - What do they look like?
  - When will they be available?
  - Environmental compliance and life cycle analysis of greenhouse gases
- The process to qualify
  - Technology Readiness Levels (TRLs)
  - ASTM-based process for qualification and approval of new fuels
- What has been done so far – some examples
  - TRL 1-4: Fuel properties
  - TRL 5-6: Component / engine evaluations
  - TRL 7-8: System evaluations
- Approval of alternatives to JP-8
  - Army requirements and JP-8 spec
  - Status of approvals for aviation platforms (JP-8, Jet A-1)

TARDEC Mission

- Provides full life-cycle engineering support and is provider-of-first-choice for all DOD ground combat and combat support vehicle systems.

- Develops and integrates the right technology solutions to improve Current Force effectiveness and provide superior capabilities for the Future Force.

Ground Systems Integrator for the Department of Defense

Responsible for Research, Development and Engineering Support to *2,800* Army systems and many of the Army's and DOD's Top Joint Warfighter Development Programs

RDECOM

TARDEC Portfolio

TARDEC

Force Projection

- Fuel & Water Distribution
- Force Sustainment
- Construction Equipment
- Bridging
- Assured Mobility Systems

Combat Vehicles

- Heavy Brigade Combat Team
- Strykers
- MRAPs
- Ground Combat Vehicles (Future)
- Abrams Main Battle Tank
- Bradley Fighting Vehicle

Tactical Vehicles

- HMMWVs
- Trailers
- Heavy, Medium & Light Tactical Vehicles
- Joint Tactical Vehicle (Future)

Robotics

- TALON
- PackBot
- MARCbot
- Gladiator
- Demonstrators
- Technology Components

TARDEC Engineers Provide Cradle-To-Grave Engineering Support

Chartered by Secretary of the Army 21 June 1993

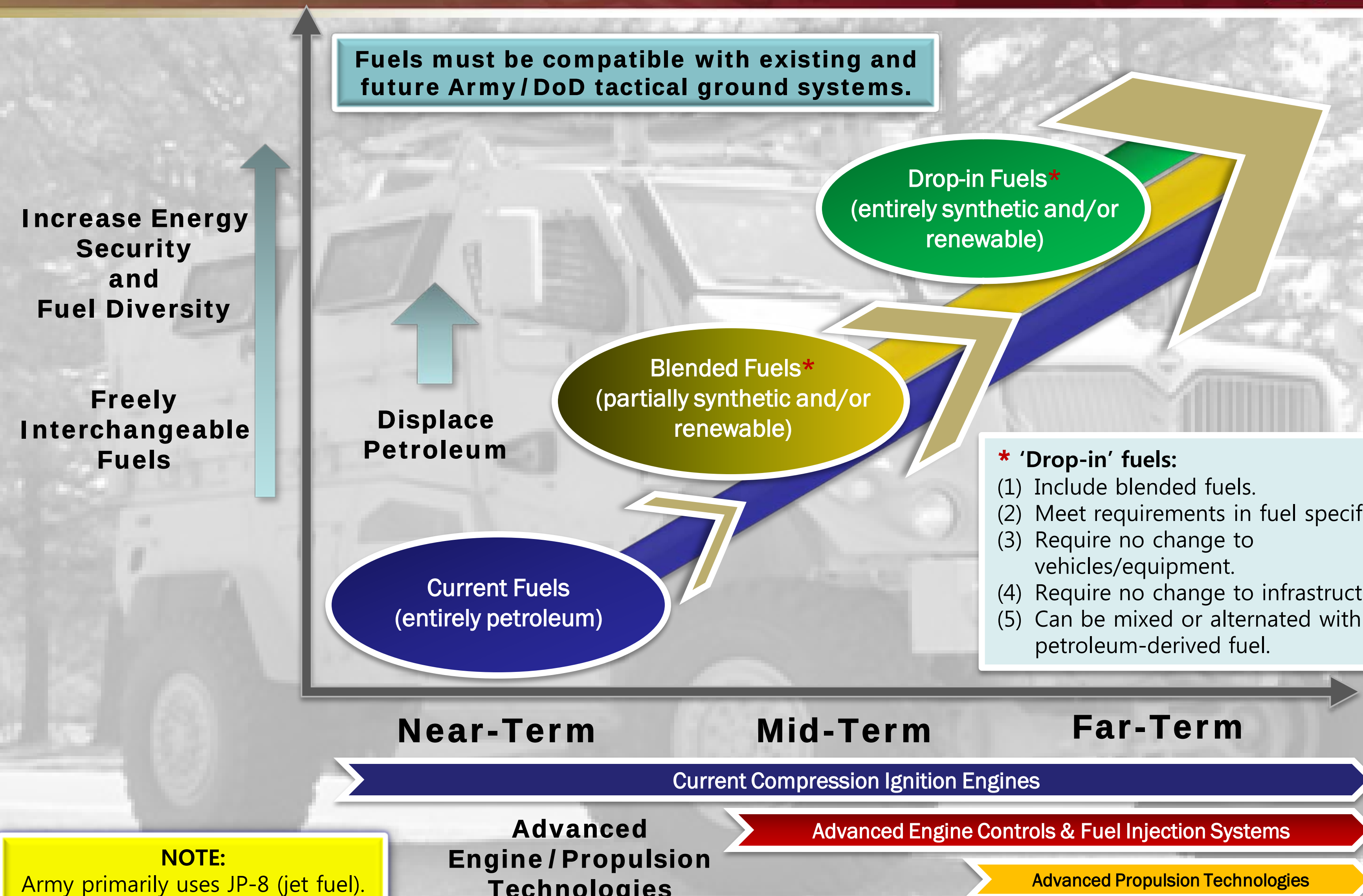
Mission: ***"The Center will serve as the Army focal point for the development of dual-use automotive technologies and their application to military ground vehicles. It will focus on facilitating joint efforts between industry, government and academia in basic research, collaboration, technology, industrial base development and professional development."***

"Leveraging Opportunities to Fill Technology Gaps."

The need to qualify alternatives to JP-8

Army Bulk Fuel Roadmap

Fuels must be compatible with existing and future Army/DoD tactical ground systems.



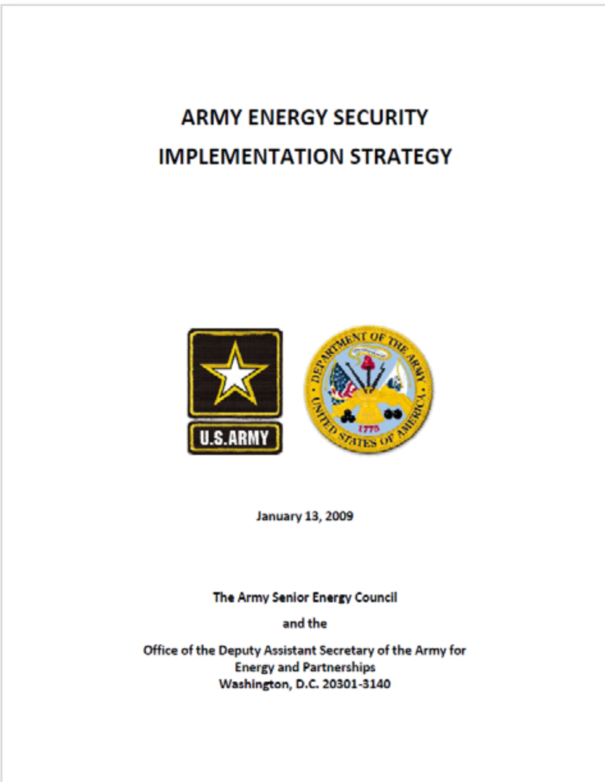
*** 'Drop-in' fuels:**

(1) Include blended fuels.
(2) Meet requirements in fuel specification.
(3) Require no change to vehicles/equipment.
(4) Require no change to infrastructure.
(5) Can be mixed or alternated with petroleum-derived fuel.

NOTE:
Army primarily uses JP-8 (jet fuel). Diesel fuel, regionally sourced, is likely alternate if JP-8 is not available or accessible.

Army Energy Security Core Characteristics

Core Characteristics defining the ***Energy Security*** necessary for the full range of Army missions:


ARMY ENERGY SECURITY

IMPLEMENTATION STRATEGY

January 13, 2009

The Army Senior Energy Council

and the

Office of the Deputy Assistant Secretary of the Army for
Energy and Partnerships
Washington, D.C. 20301-3140

Surety: Preventing loss of access to power and fuel sources.

Survivability: Ensuring resilience in energy systems.

Supply: Accessing alternative and renewable energy sources available on installations.

Sufficiency: Providing adequate power for critical missions.

Sustainability: Promoting support for the Army's mission, its community, and the environment.

Army Energy Security Goals

Strategic Energy Security Goals (ESGs)

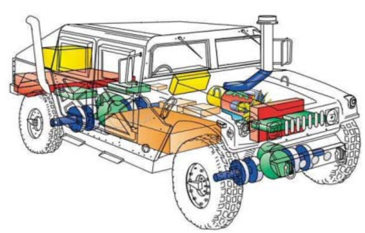
ESG 1: Reduced energy consumption.

ESG 2: Ensuring resilience in energy systems.

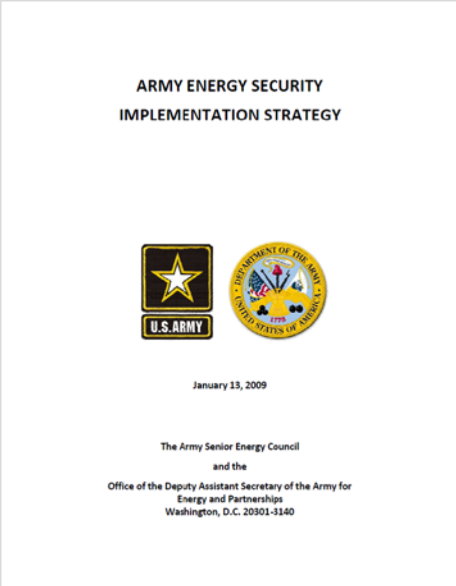
ESG 3: Increased use of renewable/alternative energy.

ESG 4: Assured access to sufficient energy supplies.

ESG 5: Reduced adverse impacts on the environment.



Army Energy Strategy Plan (Fuels Related)



ARMY ENERGY SECURITY
IMPLEMENTATION STRATEGY

U.S. ARMY

January 13, 2009

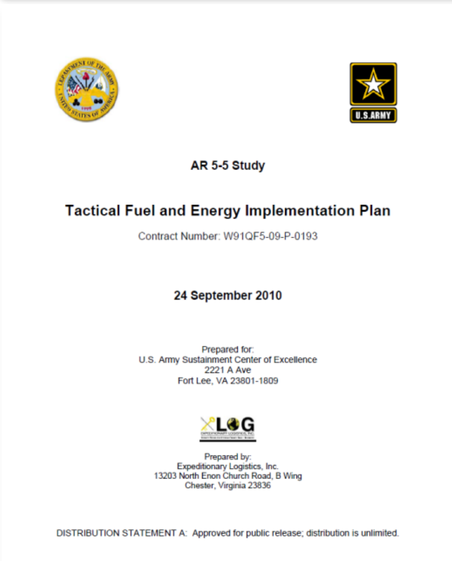
The Army Senior Energy Council
and the
Office of the Deputy Assistant Secretary of the Army for
Energy and Partnerships
Washington, D.C. 20301-3140

Strategic Energy Security Goal 3

Increased Use of Renewable / Alternative Energy

Objective 3.3

Transition from fossil fuel based tactical mobility/power generation to renewable and alternative energy/sources.



U.S. ARMY

AR 5-5 Study

Tactical Fuel and Energy Implementation Plan

Contract Number: W91QF5-09-P-0193

24 September 2010

Prepared for:
U.S. Army Sustainment Center of Excellence
2221 A Ave
Fort Lee, VA 23801-1809

XLOG

Prepared by:
Expeditionary Logistics, Inc.
13203 North Enon Church Road, B Wing
Chester, Virginia 23836

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Implementation Plan per AR 5-5 Study:

By 2028, 50% of the fuel requirement in the training base for the tactical mobility fleet (surface and air) is met by alternative fuel blends.

- Intended outcomes focused on integrating the use of alternative fuels in vehicle and aircraft engines in the training base
- Percent of fuel requirement met by alternative fuel blends:

15% by FY18
30% by FY23
50% by FY28

Air Force Energy Strategy Plan (Fuels Related)

- 2009: *Energy Management:* Air Force Policy Directive 90-17 and Air Force Instruction 90-1701
  - Lays out goals, objectives and metrics for Air Force Energy
  - Cross functional governance over the whole command
- 2011: Certification of all systems on 50%/50% FT SPK/JP-8 blend
- 2013: Certification of all systems on 50%/50% HRJ/JP-8 blends
- 2016: Obtain 50% of CONUS fuel from domestic synthetic and renewable fuels that are greener than petroleum baseline and are cost competitive

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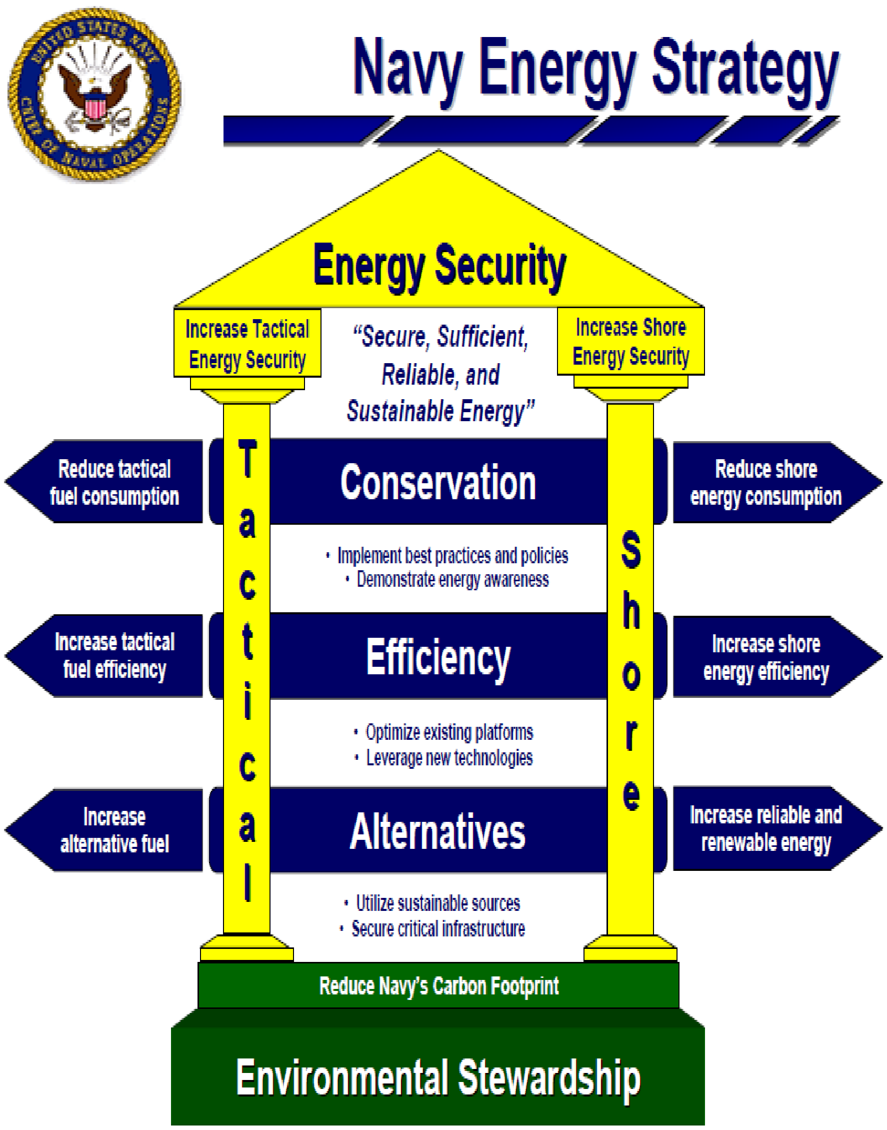
Navy Energy Strategy Plan (Fuels Related)



- 2009: Navy Energy Plan released by Chief of Naval Operations
  - Plan with aggressive 5, 10, 20 and 30 year targets for tactical shore operations
- 2012: Demonstrate the Green Strike Group ("Great Green Fleet")
- 2015: Reduce petroleum use in non-tactical fleet by 50%
- 2016: Sail the "Great Green Fleet"
- 2020: 50% of Navy Energy use from alternative energy sources

Paving The Way For Increased Use Of Alternative Fuels

EMERGING
ALTERNATIVE FUELS MARKET

- **DOD**
- **DOE**
- **Industry**
- **Academia**
- **Fuel Producers**
- **Equipment OEMs**
- **Other Government Agencies**
- **Standards Development Organizations**

Market Connection
- Fuels: process technology, data, test volumes
- Engines: combustion/fuel injection technology
- Market: regulations, policies, initiatives

Develop fuel specifications and qualify new fuels to ensure their suitability for use in ground equipment.

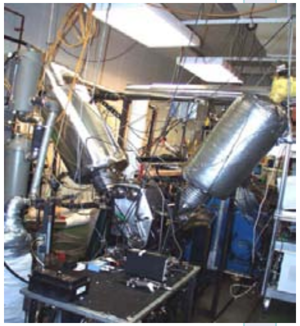
Develop engines more adaptable to changes in fuel quality/supply.

Fuel / Component Evaluations
- Chemical composition
- Physical properties
- Component performance / durability

Engine Evaluations
- Fuel ignitability
- Fuel combustion
- Performance / durability

System Evaluations
- Operability
- Performance
- Demonstrations

Fuel Qualification Process for approval of new fuels

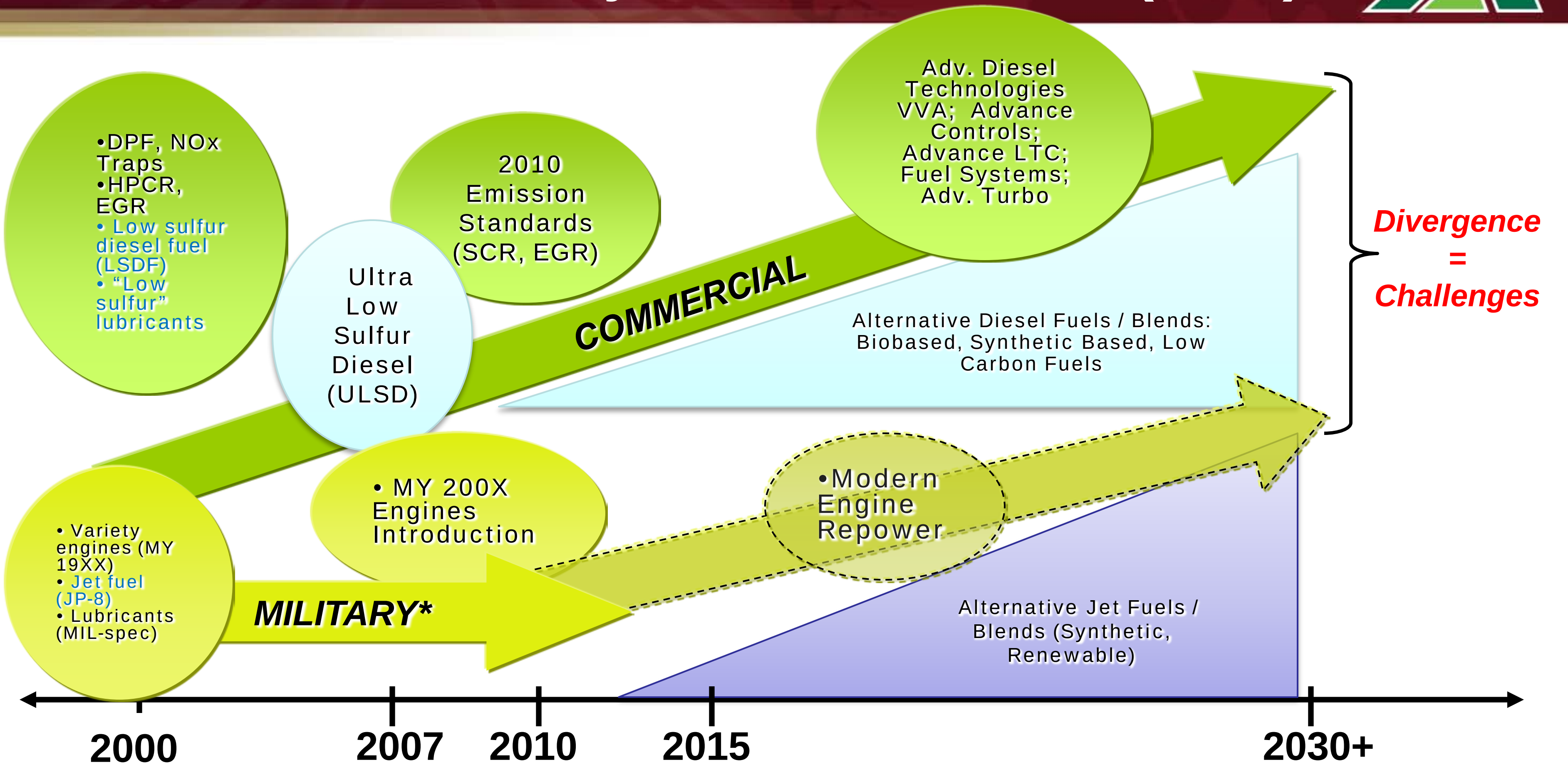


Wayne State University Photo courtesy of N. A. Henein, WSU

Self-adjusting engine operation with changes in fuel quality to maintain desired engine performance

Acceptance of alternative fuels for use in ground vehicles/equipment.

Diesel Market – Military vs. Commercial (U.S.)

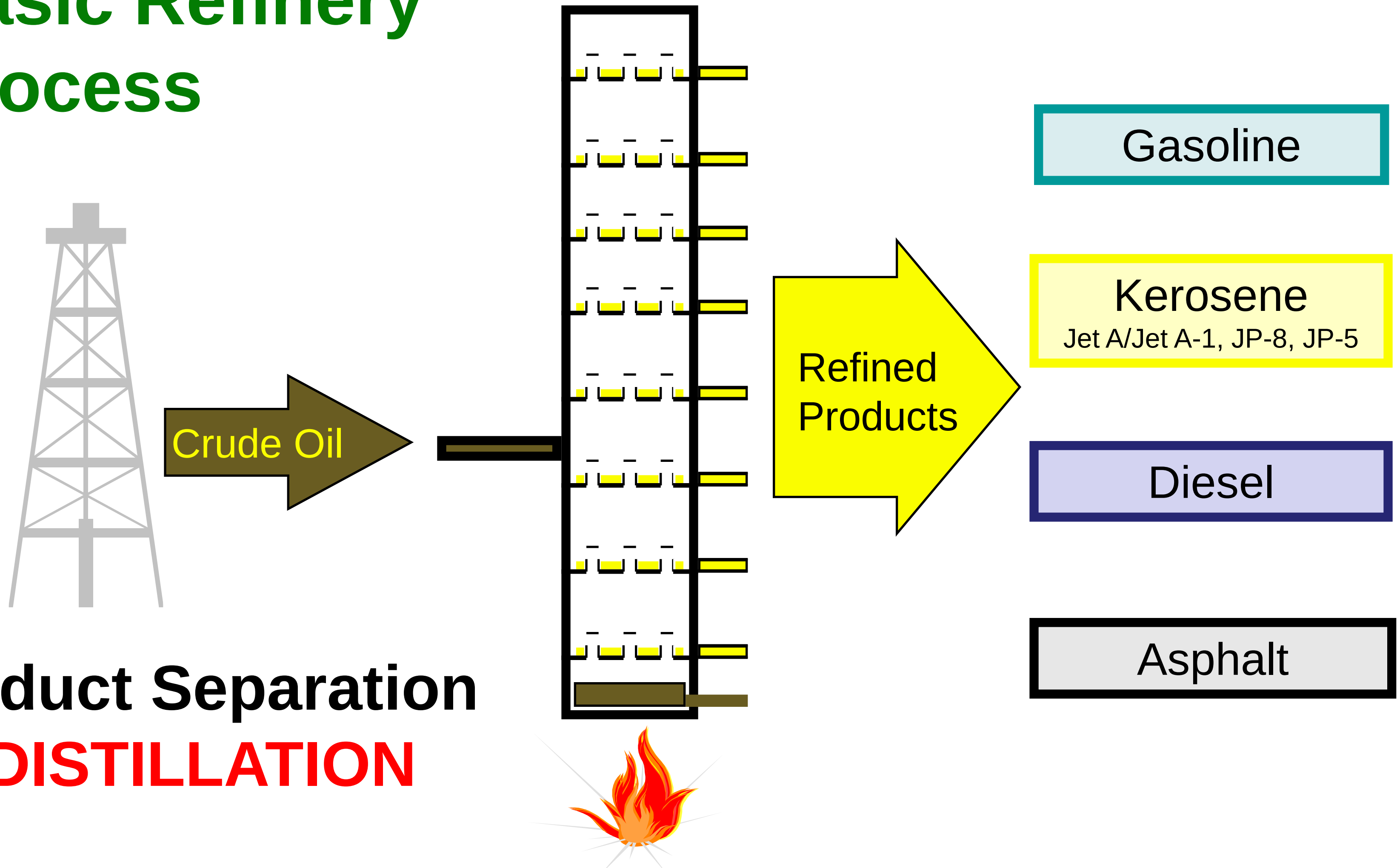


Diesel engine technologies will continue to evolve and alternative fuels will continue to emerge into the fuels supply. As these changes occur, the Army needs to understand the extent and nature of them to ensure Army capability is not adversely affected, but rather it is enhanced by knowing how to integrate them.

JP-8 logistical fuel

Used with permission from Rick Kamin, Fuels Lead, Navy Energy Coordination Office (modified)

Basic Refinery Process



Product Separation by DISTILLATION

Aviation / Jet Fuel Lexicon

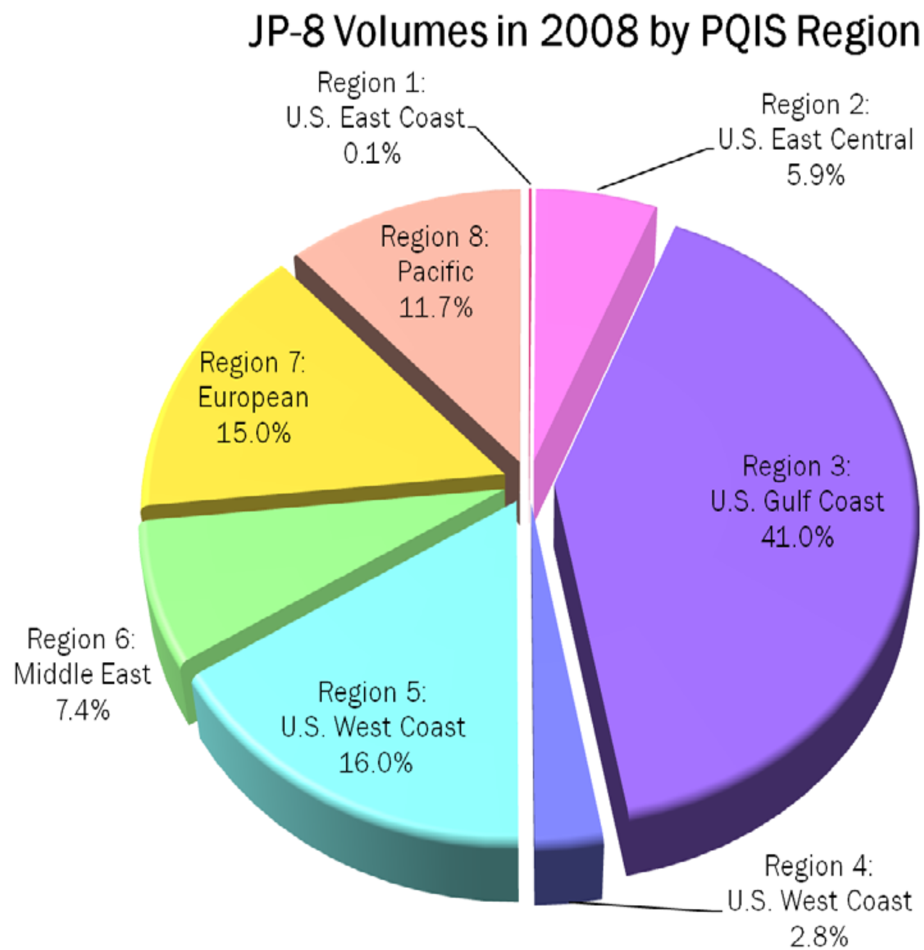
- Jet A / Jet A-1
  - Majority of commercial jet fuel used worldwide
  - Manufactured to meet ASTM D1655 or UK Def Stan 91-91 specifications
  - Jet fuel specifications are highly harmonized to accommodate the international nature of aviation travel
- Jet Propellant 8 (JP-8)
  - Primary fuel used by USAF and USA, including tactical/combat ground equipment
  - Manufactured to meet MIL-DTL-83133 (USAF-maintained)
  - Commercial Jet A-1 containing mandatory military-approved additives (discussed in upcoming slides)
- Jet Propellant 5 (JP-5)
  - Used by USN ship-based aircraft
  - Manufactured to meet US MIL-DTL-5624 (USN-maintained) or UK DEF STAN 91-86
  - Key difference from JP-8 is a higher flash point to improve safety for onboard ship-use

Jet Fuels – Commercial versus Military JP-8

- Commercial
  - Jet A or Jet A-1 (same except freeze point)
  - ASTM D1655 and UK Def Stan 91-91 are key specifications
- Military JP-8
  - Specified by MIL-DTL-83133
  - JP-8 is Jet A-1 containing three military-approved additives
    1) Fuel System Icing Inhibitor (FSII)
    2) Static Dissipator Additive (SDA)
    3) Corrosion Inhibitor/Lubricity Improver (CI/LI)
       - Minimum concentration of CI/LI in QPL-25017 and qualified according to MIL-PRF-25017 should result in BOCLE wear scar diameter of no more than 0.65mm
  - Optional Additives
    a. Metal Deactivator Additive (MDA)
    b. Anti-oxidant (AO)

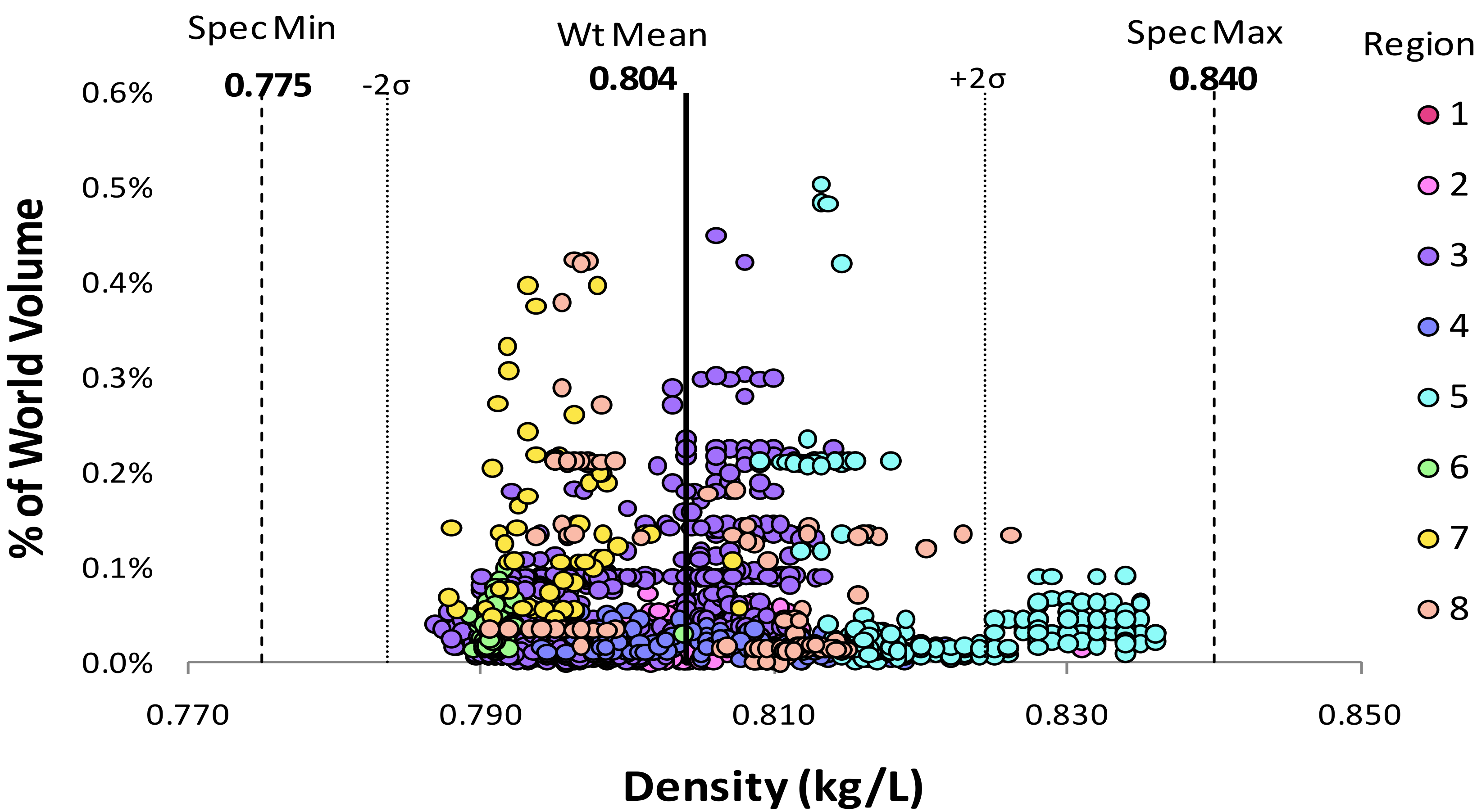
About PQIS, JP-8 Volumes in 2008

- **PQIS: P**etroleum **Q**uality **I**nformation **S**ystem
  - Facilitates collection and dissemination of standard fuel quality data
  - Annual reports issued by Defense Logistics Agency – Energy (DLA-E), formerly Defense Energy Support Center (DESC)
  - World split into12 geographical regions
- **JP-8 purchased in 2008**
  - 2.3 Billion gallons worldwide
  - Only from Regions 1-8
  - None from Regions 9-12
  - JP-8 properties vary by region based upon crude and processing (see slides 20-26)



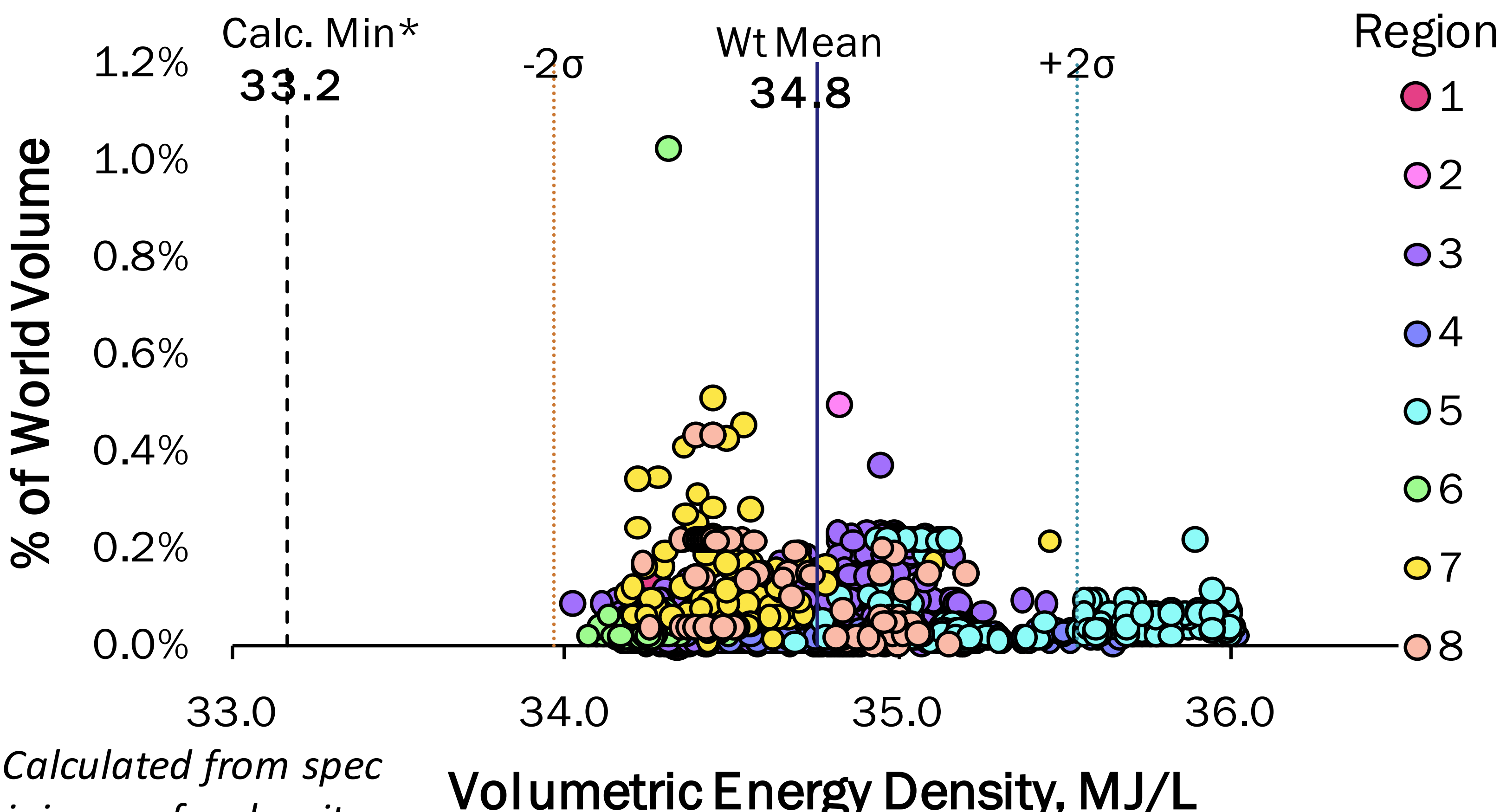
from PQIS 2008 Annual Report

JP-8 Density Distribution



from PQIS 2008 Annual Report

JP-8 Volumetric Energy Density Distribution

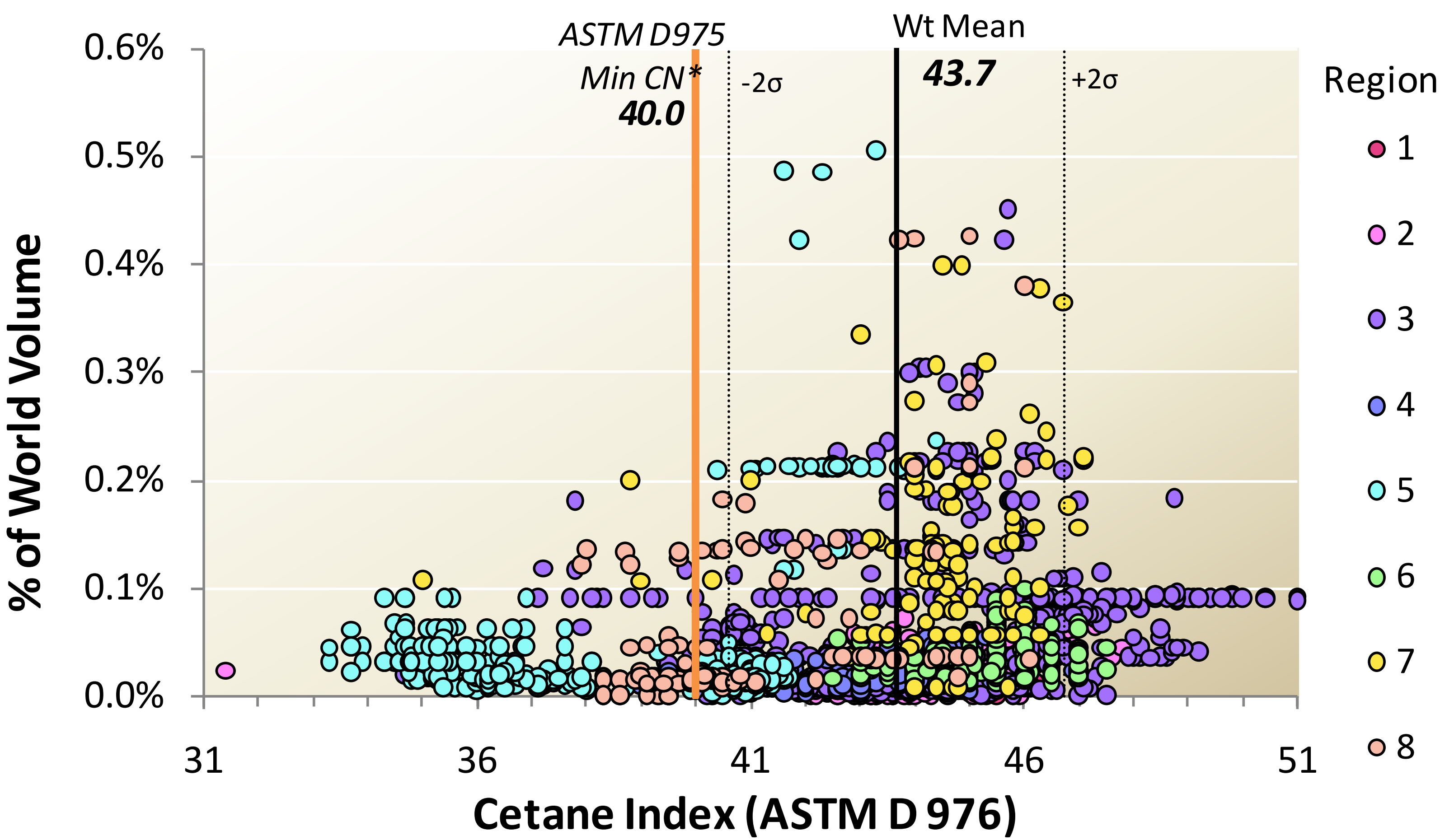


** Calculated from spec minimums for density and lower heating value*

from PQIS 2007 Annual Report

unclassified

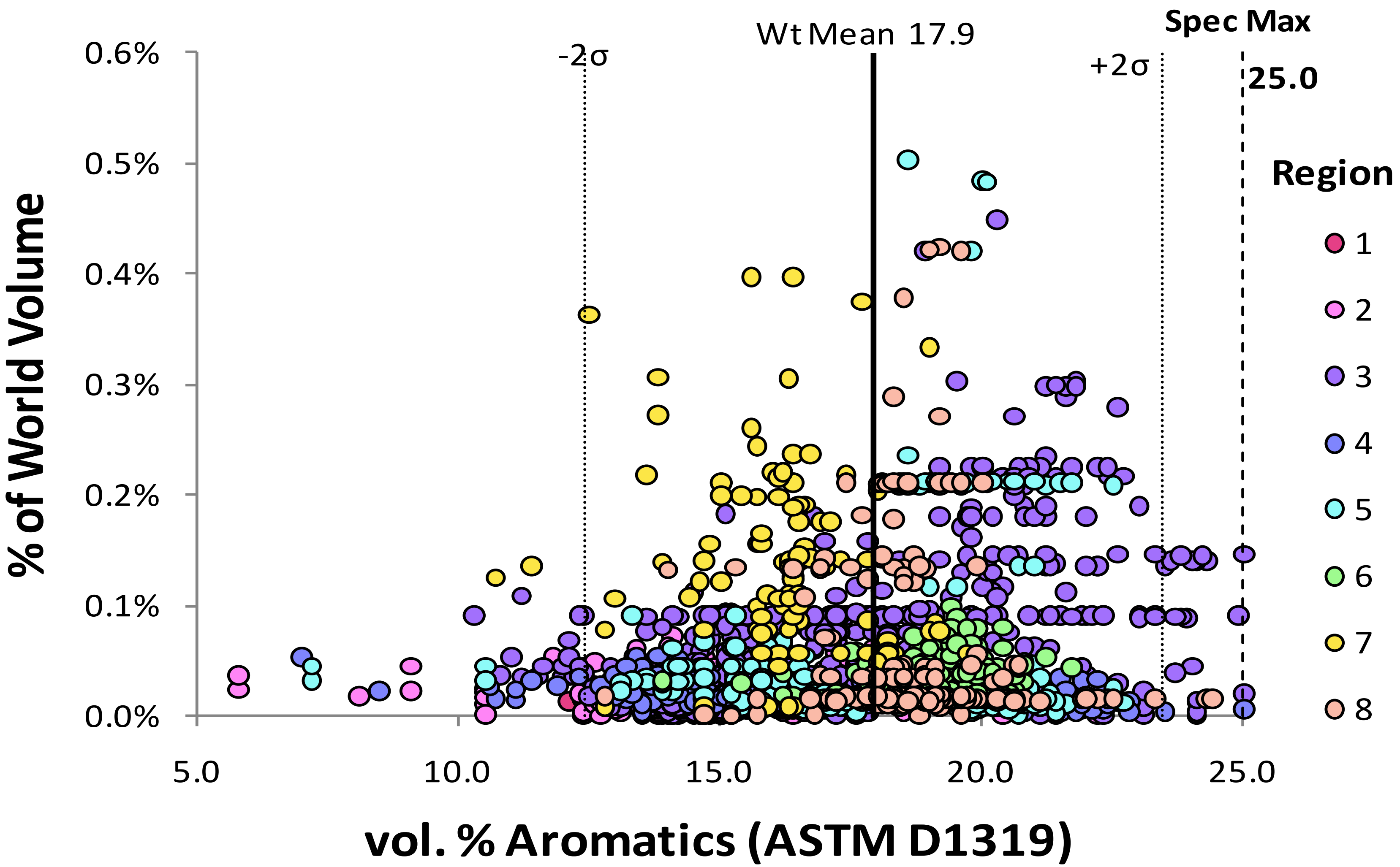
JP-8 Cetane Index Distribution



* Cetane Number (ASTM D613)

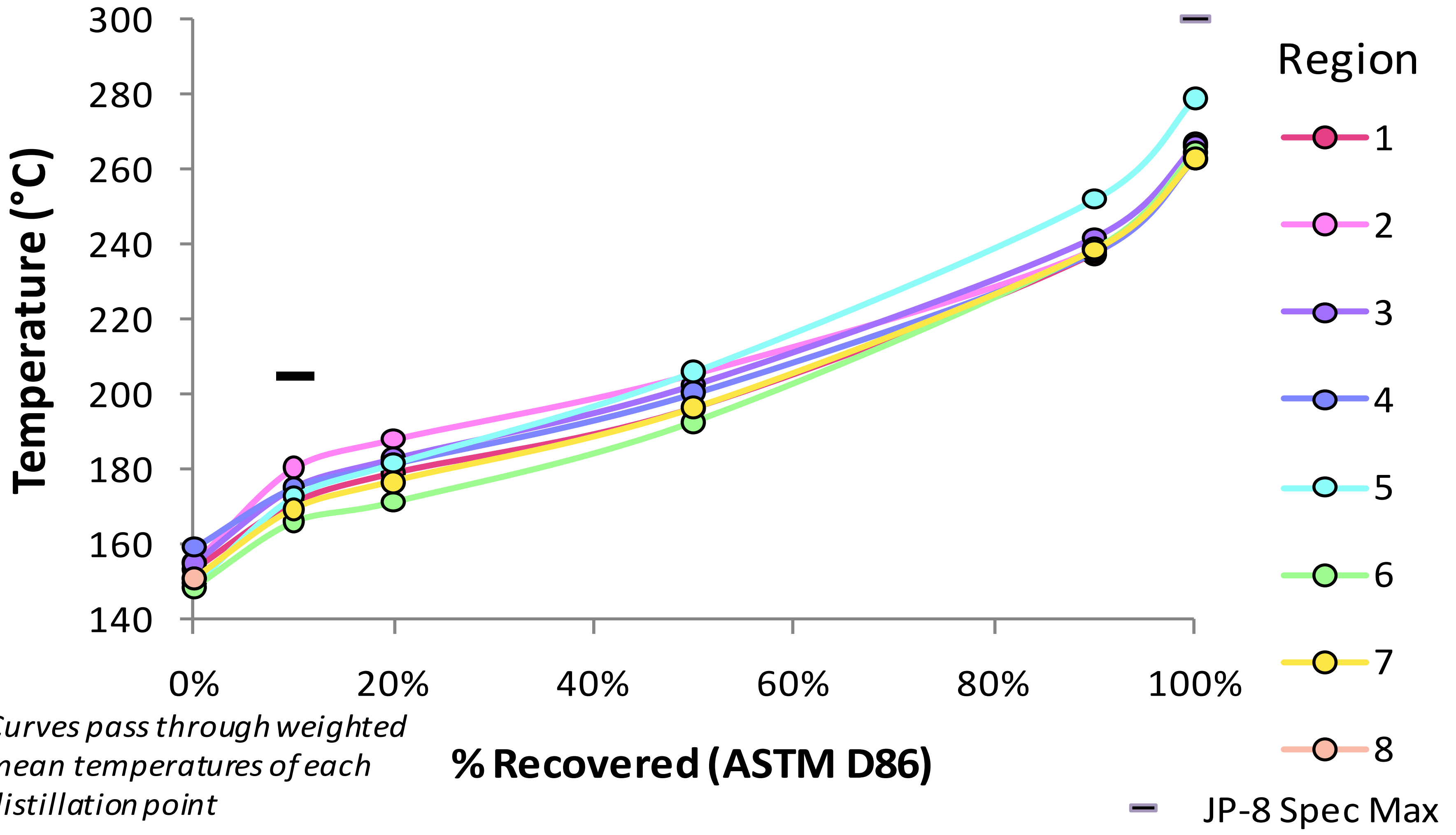
from PQIS 2008 Annual Report

JP-8 Aromatic Content Distribution



from PQIS 2008 Annual Report

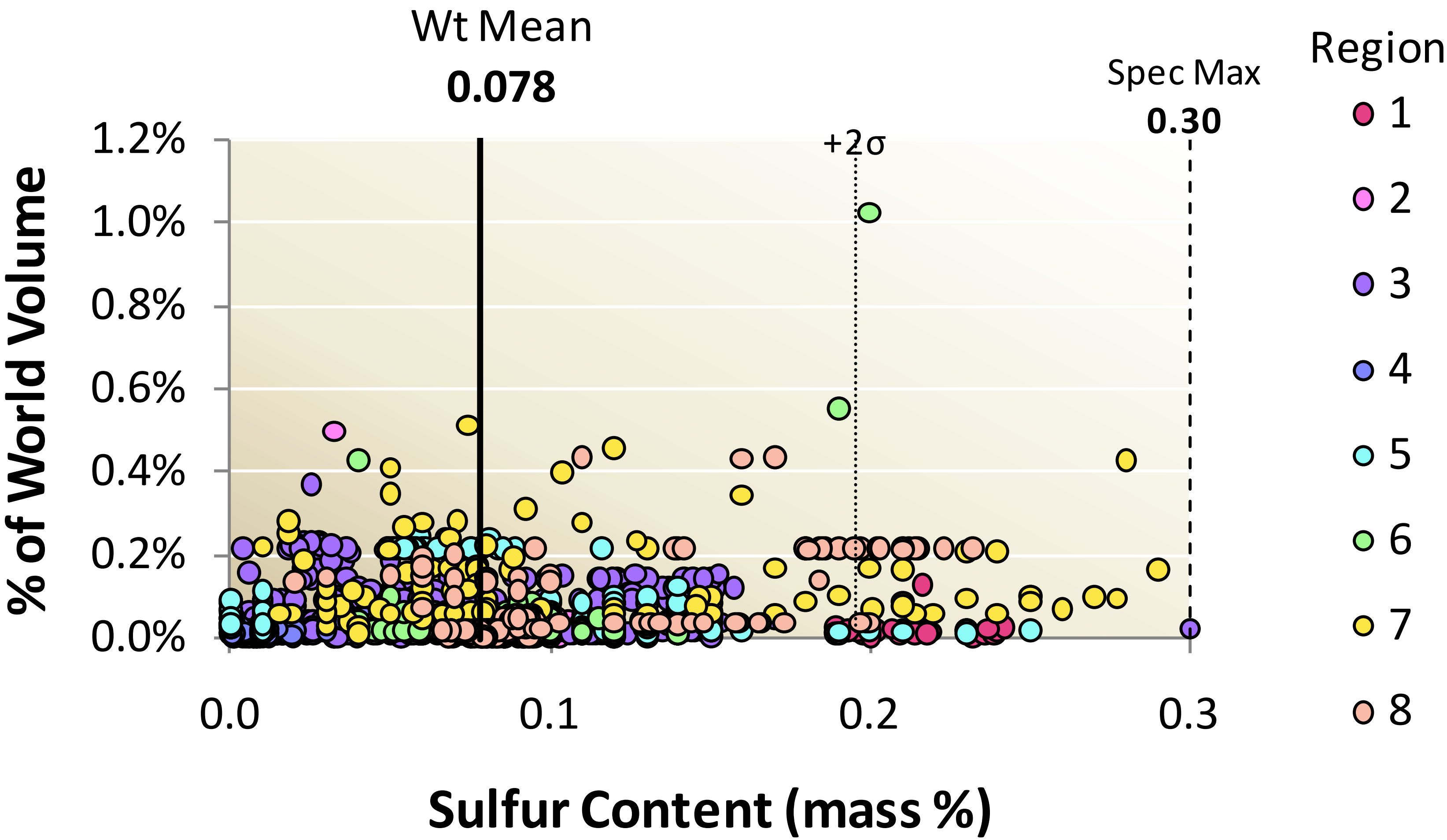
JP-8 Boiling Point Distribution (Distillation Curves)



Curves pass through weighted mean temperatures of each distillation point

from PQIS 2008 Annual Report

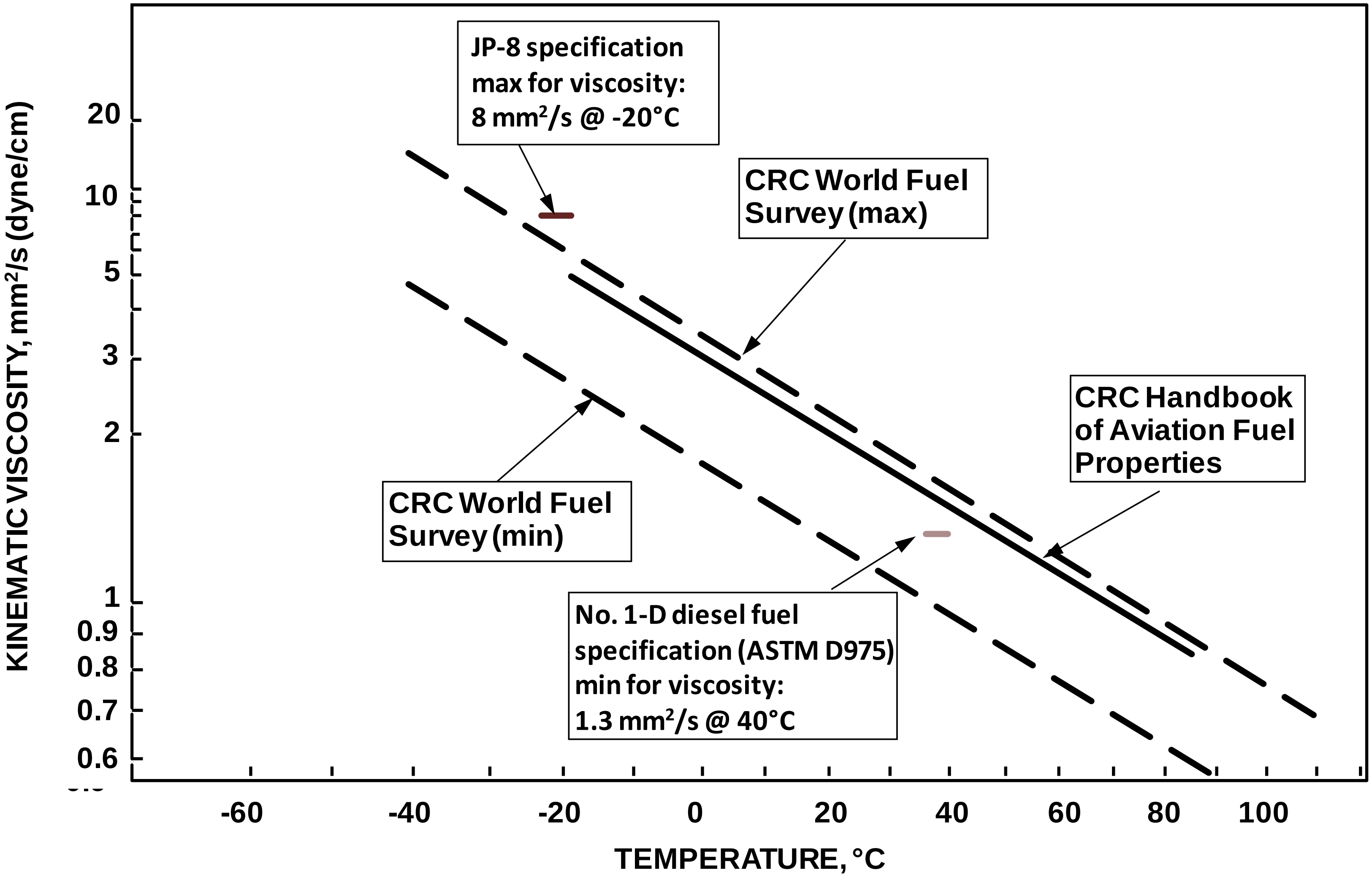
JP-8 Sulfur Content Distribution



from PQIS 2007 Annual Report

JP-8 Viscosity

Used with permission from CRC, Executive Director



Source: CRC Report No. AV-2-04a

How Do Jet and Diesel Fuels Differ?
(some key requirements in their specifications)

	Diesel Fuel Specification ASTM D975				Jet Fuel Specifications					
					Def Stan 91-91 / ASTM D1655		MIL-DTL-83133G		MIL-DTL-5624U	
Fuel Grade	DF-1		DF-2		Jet A-1		JP-8		JP-5	
Property (unit)	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Cetane Number	40	- - -	40	- - -	- - -	- - -	Report (Cetane Index)		Report (Cetane Index)	
Viscosity @ 40°C (mm^2/s)	1.3	2.4	1.9	4.1	- - -	- - -	- - -	- - -	- - -	- - -
Viscosity @ -20° C (mm^2/s)	- - -	- - -	- - -	- - -	- - -	8.0	- - -	8.0	- - -	8.5
Density @ 15°C (kg/L)	- - -	- - -	- - -	- - -	0.775	0.840	0.775	0.840	0.788	0.845
Sulfur Content (ppm)	- - -	15	- - -	15	- - -	3000	- - -	3000	- - -	3000
Flash Point (°C)	38	- - -	52	- - -	38	- - -	38	- - -	60	- - -
Lubricity HFRR @ 60°C (µm)	- - -	520	- - -	520	- - -	0.85 BOCLE (mm)	- - -	0.65* BOCLE (mm)	- - -	0.65* BOCLE (mm)

* As provided by minimum effective treat rate of mandatory lubricity improver additive per QPL-25017 and MIL-PRF-25017

Alternatives to JP-8

Terminology

Terminology	Acronym	Definition
Biomass-to-Liquids	BTL	Conversion of biomass to synthetic liquid hydrocarbons via the Fischer-Tropsch reaction
Coal-to-Liquids	CTL	Conversion of coal to synthetic liquid hydrocarbons via the Fischer-Tropsch reaction
Coal-and-Biomass-to-Liquids	CBTL	Conversion of co-fed coal and biomass to synthetic liquid hydrocarbons via the Fischer-Tropsch reaction
Gas-to-Liquids	GTL	Conversion of natural gas to synthetic liquid hydrocarbons via the Fischer-Tropsch reaction
Fischer-Tropsch Synthetic Paraffinic Kerosene	FT SPK	Kerosene manufactured synthetically via the Fischer-Tropsch reaction and subsequent processing steps
Hydroprocessed Fatty Acid Esters and Free Fatty Acids	HEFA	Esters and fatty acids derived from various feedstocks that are subsequently upgraded to components intended for use in transportation fuels (e.g., jet fuel)
Hydroprocessed Renewable Jet	HRJ	Kerosene (intended as a jet fuel component) manufactured from renewable feedstock and processed via selective hydrocracking and subsequent fractionation

Alternatives to JP-8 in Advanced Evaluation

- Two alternative fuels for which evaluations are being completed to assess their impacts on tactical ground systems
  - Blends of JP-8 and up to 50% by volume of
    - Fischer-Tropsch Synthetic Paraffinic Kerosene (FT SPK)
    - Hydroprocessed Renewable Jet (HRJ)
  - Both products (FT SPK and HRJ) are very similar compositionally
    - Resultant properties are very similar
    - Evaluations thus conducted using one of these blends will be representative of evaluations for the other by similarity
  - Evaluations are conducted using nominal 50%:50% volumetric blends
  - Blends are meant to be "drop-in" fuels
    - Meets fuel performance requirements (in spec)
    - Requires no change to vehicles/equipment
    - Requires no change to infrastructure
    - Can be mixed or alternated with petroleum-derived fuel

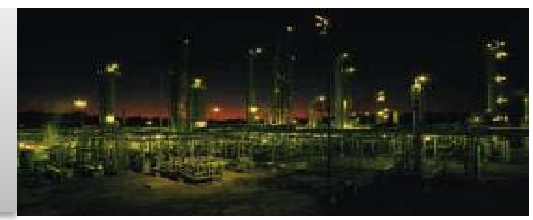
Alternatively Sourced Liquid Hydrocarbons

Biomass Feedstock (renewables)

Fossil Energy Feedstock
(large U.S. resource)

Petroleum Crude Oil
(increasingly difficult discovery and unfriendly-nation production)

- Various conversion processes dependent on feedstock
- Product meeting commercial and/or military specifications
- Specs evolving to address alternatively sourced hydrocarbons



Jet Fuel

- ASTM D1655: conventional jet fuel
- ASTM D7566: blends of synthetic kerosene with conv. jet fuel
- MIL-DTL-83133: JP-8, also blends of synthetic kerosene with JP-8

Diesel Fuel

- ASTM D975: up to 5% v. FAME biodiesel (B100) allowed in diesel fuel
- ASTM D6751: B100 spec
- ASTM D7467: blends of 6%-20% v. FAME biodiesel (B100) with diesel

DARPA Alternative Jet Fuels: Biofuels and Coal-Derived

Can alternative jet fuels be made on large-scale and be cost competitive?

2006

- ***Biofuels Phase 0***
  - Proof of concept: flexible process for agricultural crop oil feedstocks

2008

- ***Biofuels Phase 0***
  - Resulted in HRJ
- ***Biofuels Phase I & II***
  - Cellulosic Phase I Award – Goal of 30% conversion efficiency
  - Algae RFP – Demonstrate algal triglyceride production
- ***Coal-to-Liquid* RFP**

2010

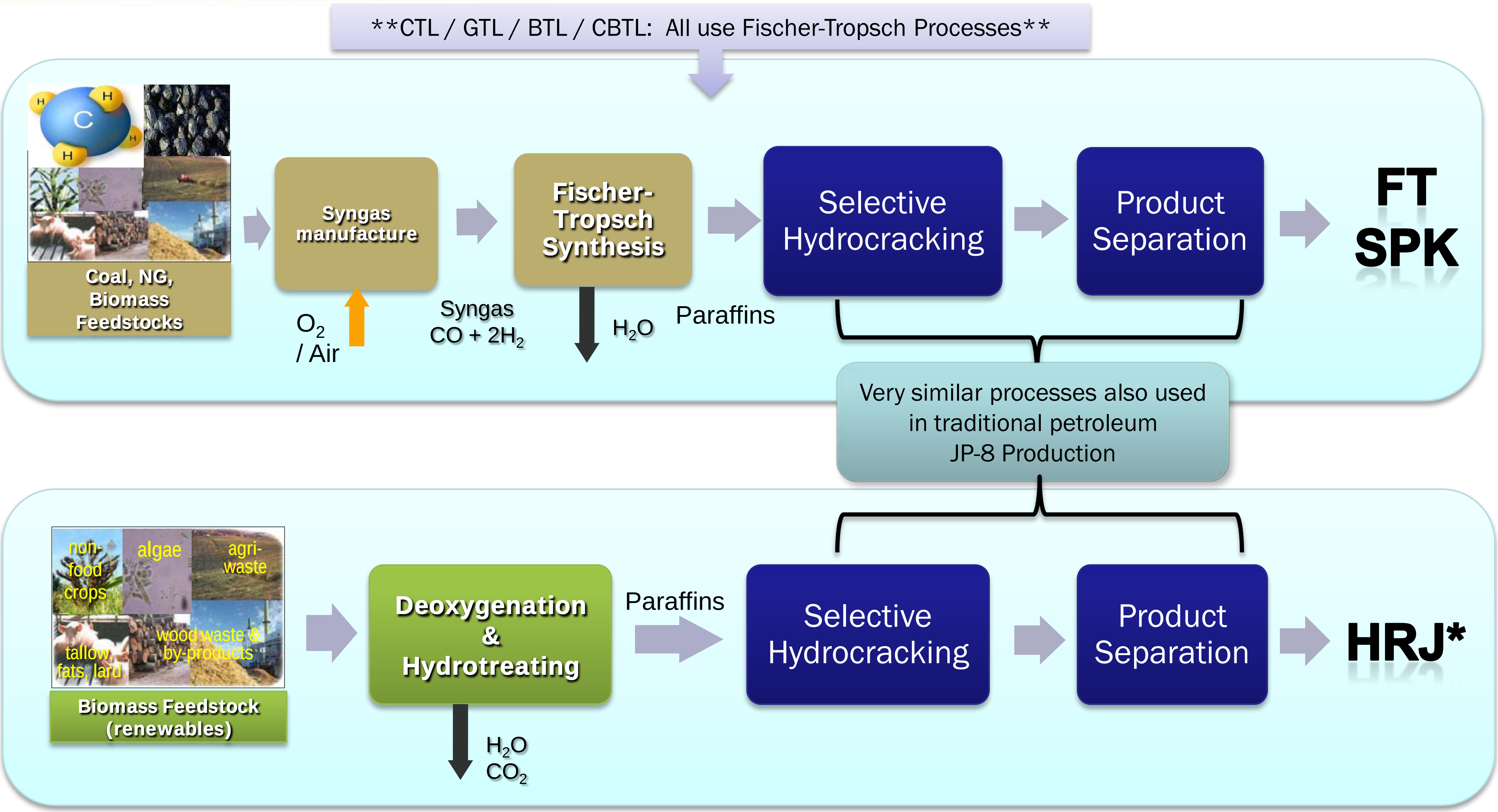
- ***Biofuels Phase I & II***
  - Cellulosic Phase II Award – Goal of 50% conversion efficiency
  - Algal Phase I Award
- ***Coal-to-Liquid* Award** – Study on feasibility of acceptable environmental and economic proof of concept

2012+

- ***Biofuels Phase I & II***
  - Cellulosic Phase II Completion
  - Algae Phase II Award – Demonstrate algal oil production at $1/gal

Goal: <$3/gal at production capacity

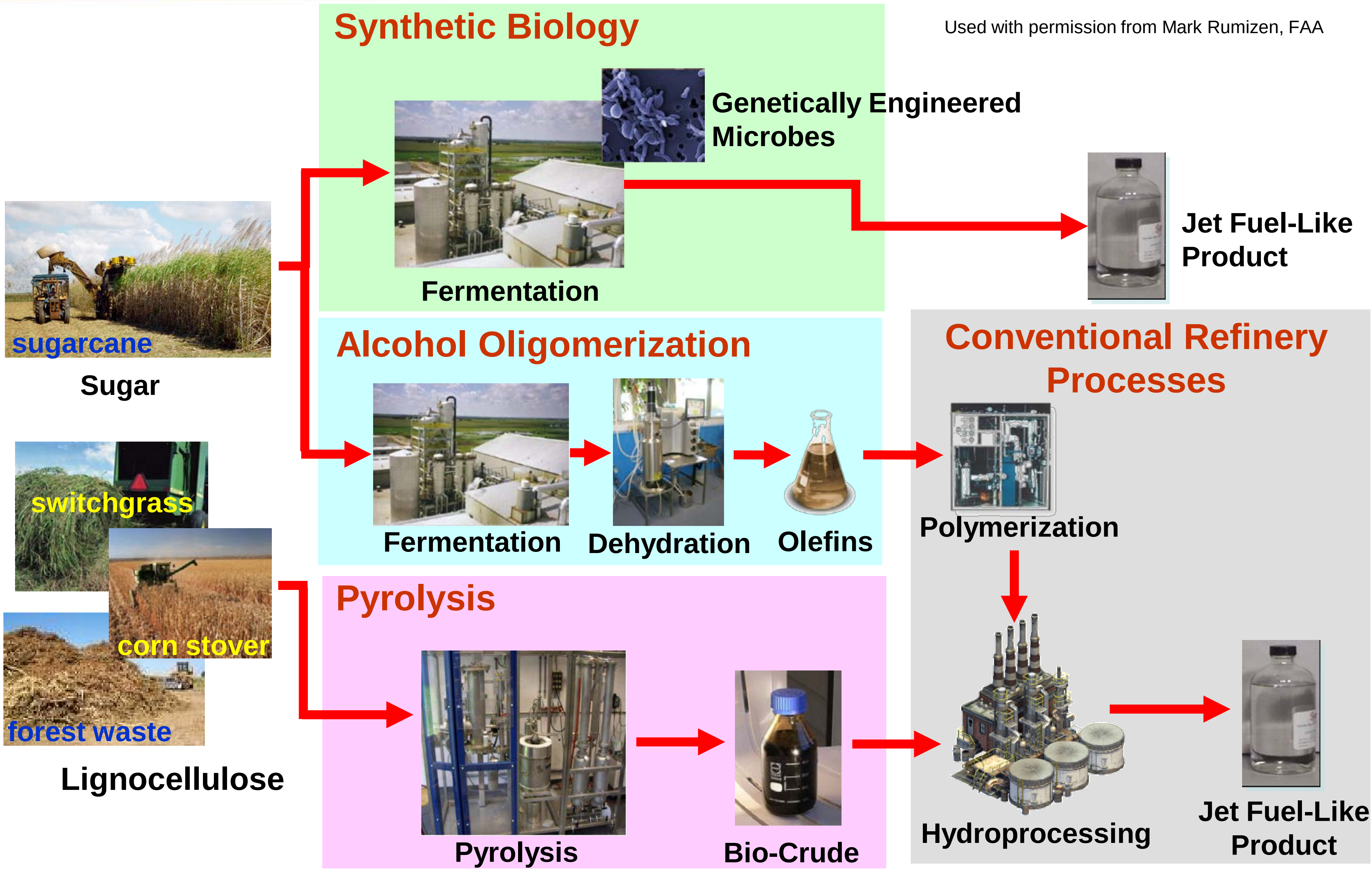
FT SPK and HRJ Blendstocks – How They Are Made



Because of the similar end-processing, FT SPK and HRJ are chemically similar blendstocks

* HRJ terminology may change to Hydroprocessed Fatty Acid Esters and Free Fatty Acids (HEFA)

More Possibilities For Making Alternative Jet Fuels (or Blendstocks)



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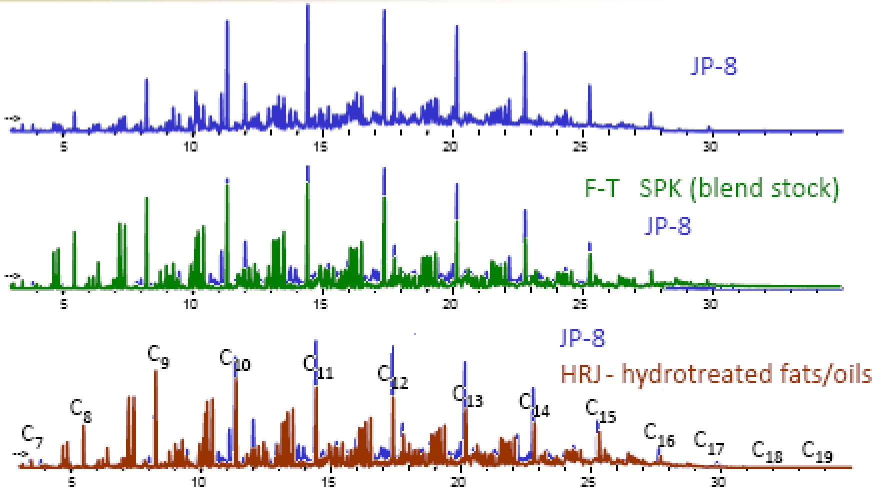
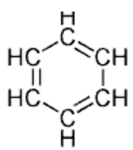
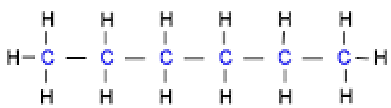
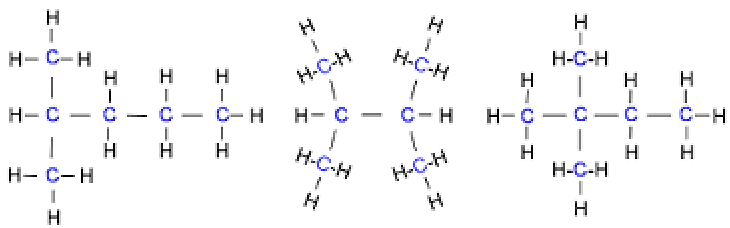
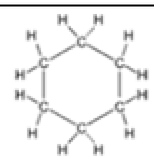
Courtesy of Rick Kamin, Fuels Lead, Navy Energy Coordination Office



ASTM D2425 – GC/MS Indicates Similarity of Size & Type of Hydrocarbon Molecules in Fuel

		JP-8	HRJ	FT SPK
	**aromatics**	20%	<0.5%	<0.1%
	**n-paraffins**	59%	>84.5%	99%
	**iso-paraffins**			
	**cyclo-paraffins**	20%	<15%	<0.1%

Key Requirements – JP-8, FT SPK, and Fuel Blends of These

Property	JP-8		Blend		SPK	
	min	max	min	max	min	max
Aromatics (vol %)		25.0	8.0	25.0		0.5
Sulfur total (mass %)		0.30		0.30		0.0015
Cycloparaffins (mass %)						15.0
Distillation temperature, ˚C						
10% recovered (T_{10})		205		205		205
Final boiling point		300		300		300
T_{50}-T_{10}			15			
T_{90}-T_{10}			40		22	
Density @ 15˚C (kg/L)	0.775	0.840	0.775	0.840	0.751	0.770
Calculated cetane index	Report		Report		Report	
Viscosity @ -20˚C (mm^2/s)		8.0		8.0		8.0
Viscosity @ 40˚C (mm^2/s)					Report	
Net Heat of Combustion (MJ/kg)	42.8		42.8		42.8	
Lubricity, BOCLE (WSD, mm)		0.65*		0.65*		

* As provided by minimum effective treat rate of mandatory lubricity improver additive per QPL-25017 and MIL-PRF-25017

- Requirements for all three products are found in MIL-DTL-83133G
- Most requirements for the blend, including all of those not shown, are the same as JP-8 for “drop-in” capability of the blends

FT SPK Blend Spec, and Properties of Some FT SPK and HRJ Blends

		AF-7117	FL-12972-08	POSF 6406	POSF 6184
Properties	JP-8 / FT SPK Blend Specification MIL-DTL-83133G	Shell FT SPK Blend[1]	Syntroleum FT SPK Blend[2]	UOP HRJ Blend Tallow	UOP HRJ Blend Camelina
Aromatics (vol %)	8.0 - 25.0	9.3	14.0	9.3	10.1
Sulfur total (mass %)	0.30 max	ng	ng	0.02	0.02
Distillation Temperature, °C					
10% recovered (T_{10})	205 max	170	179	180	170
FBP	300 max	239	257	261	275
T_{50}-T_{10}	15 min	15	22	30	29
T_{90}-T_{10}	40 min	64	53	64	72
Density @ 15˚C (kg/L)	0.775 - 0.840	0.774	0.792	0.781	0.778
Viscosity @ -20˚C (mm^2/s)	8.0 max	-	4.4	5.0	4.0
Viscosity @ 40˚C (mm^2/s)		1.2	1.3	1.4	1.2
Net Heat of Combustion (MJ/kg)	42.8 min	43.4	43.3	43.8	43.8
Derived Cetane Number[3]		48.8	47.0	49.4	49.2
Calculated cetane Index	Report	46.6	48.0	57.1	55.1
Lubricity - BOCLE (mm)		0.55	0.53	0.55	0.53

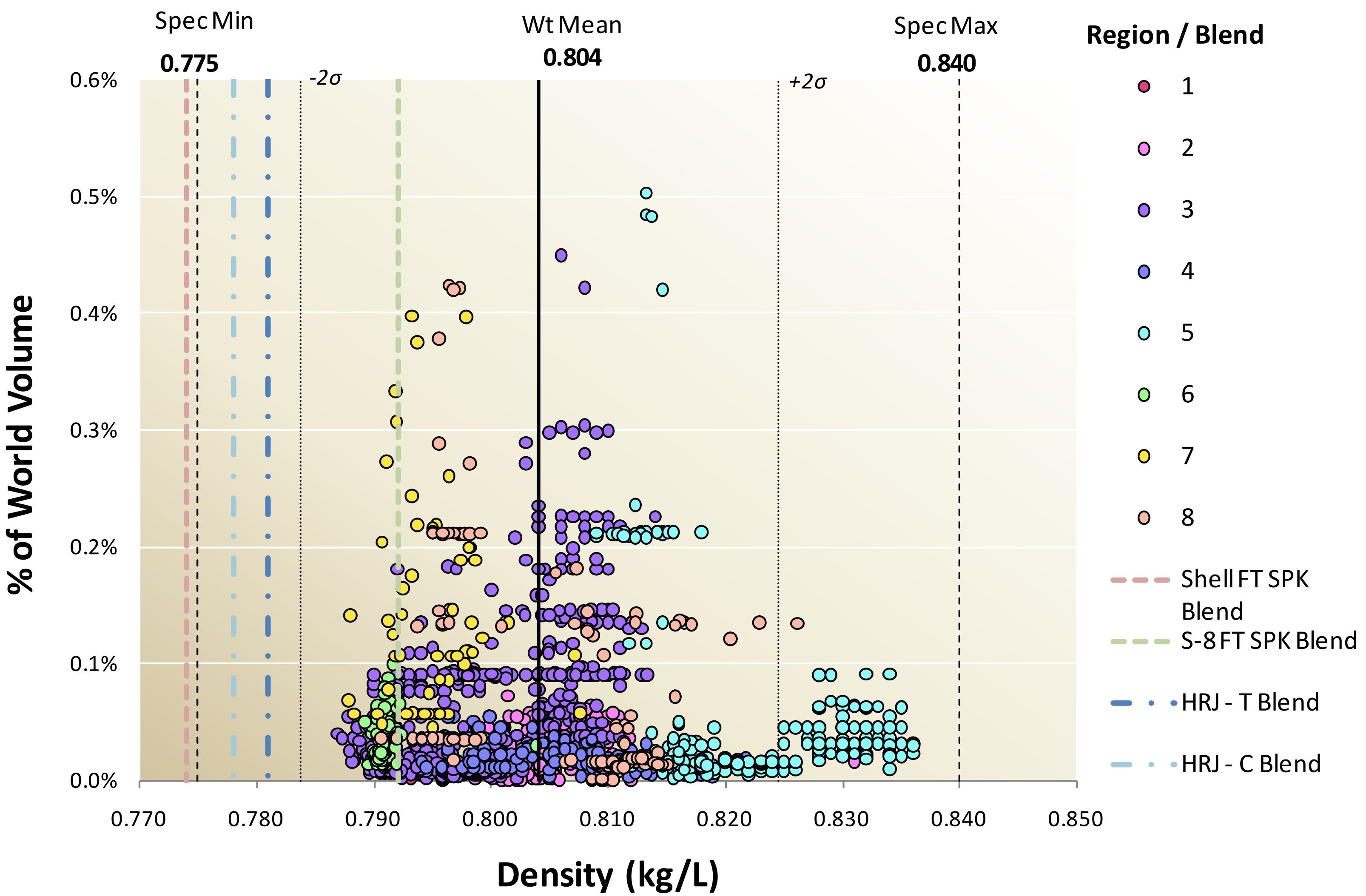
NOTES:

1. Shell FT SPK purchased on waiver – density did not meet minimum requirement per MIL-DTL-83133 REV F; this product does not meet REV G either, but is being tested (50%:50% v. blend) as "worst case" scenario.

2. Syntroleum "S-8" FT SPK is a nominal representative blend stock meeting MIL-DTL-83133G.

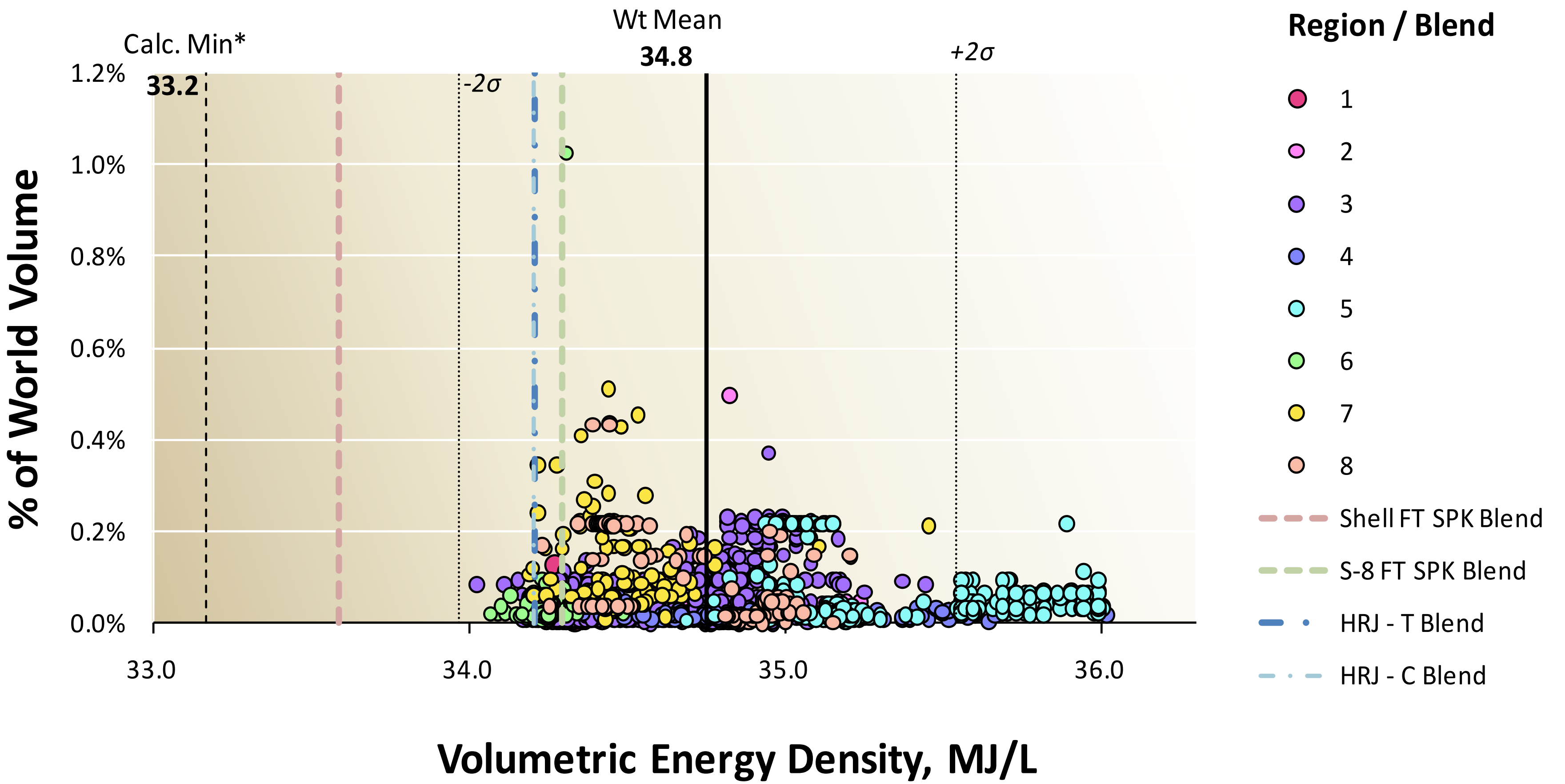
3. While not a required property, Derived Cetane Number is a more accurate representation of Cetane Number (ASTM D613) than is Calculated Cetane Index (ASTM D976, ASTM D4737) for some fuels such as synthetic fuels.

Density: JP-8 Distribution vs. Fuel Blends



from PQIS 2008 Annual Report

Volumetric Energy Density: JP-8 Distribution vs. Fuel Blends

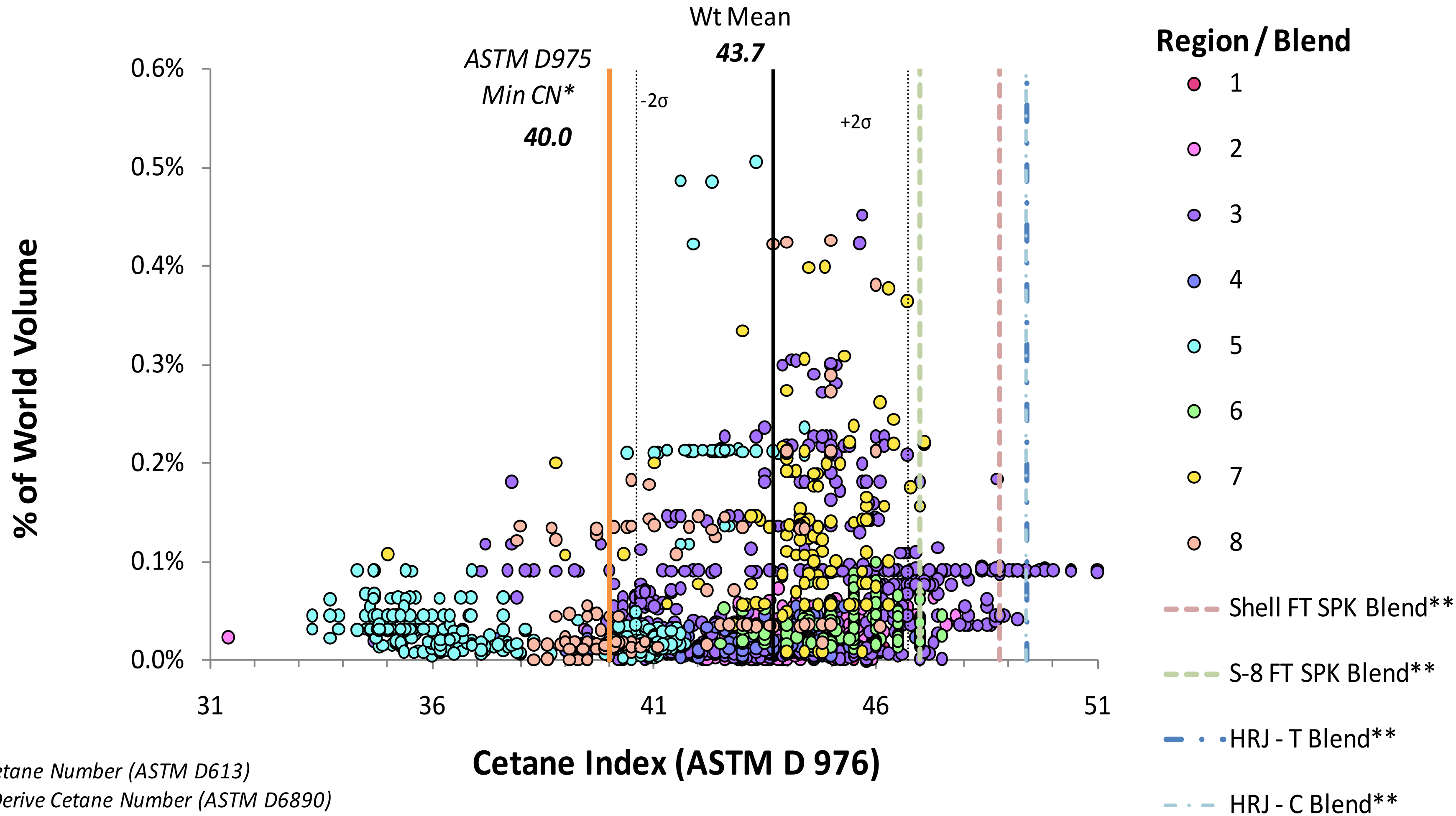


** Calculated from spec minimums for density and lower heating value*

from PQIS 2007 Annual Report

unclassified

Cetane Index: JP-8 Distribution vs. Fuel Blends**

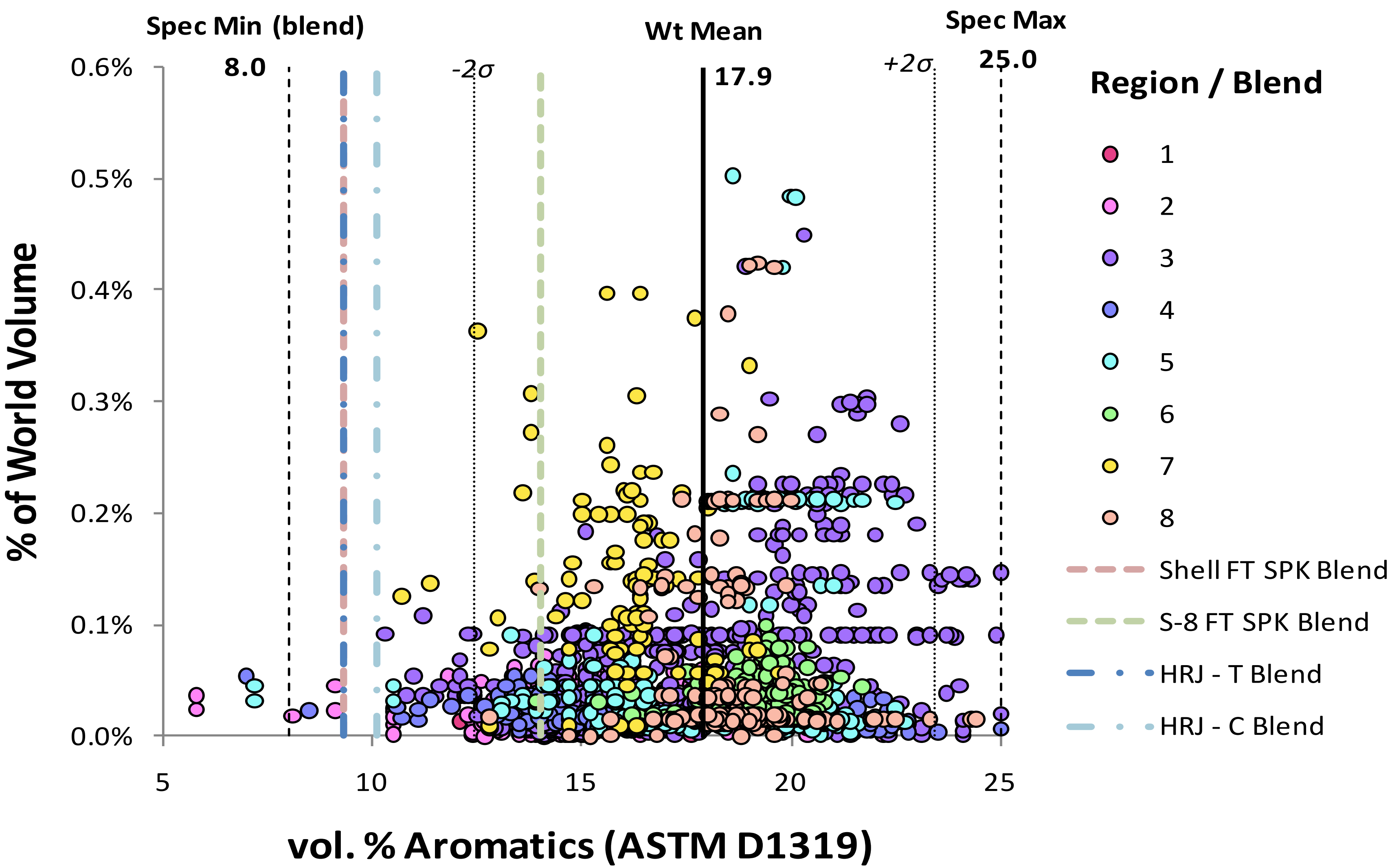


* Cetane Number (ASTM D613)

**Derive Cetane Number (ASTM D6890)

from PQIS 2008 Annual Report

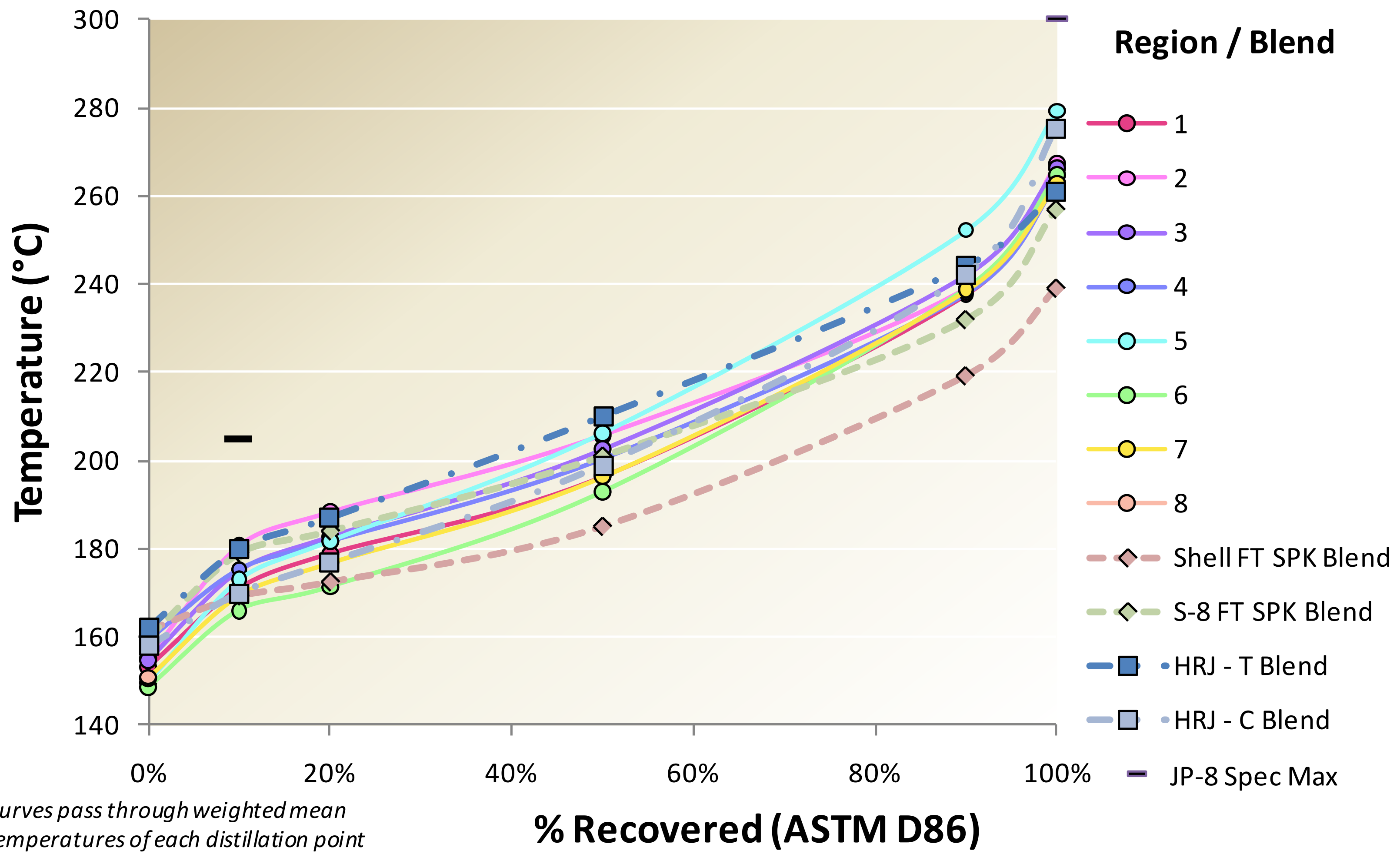
Aromatic Content: JP-8 Distribution vs. Fuel Blends



from PQIS 2008 Annual Report

unclassified

Boiling Point: JP-8 Distribution vs. Fuel Blends (Distillation Curves)

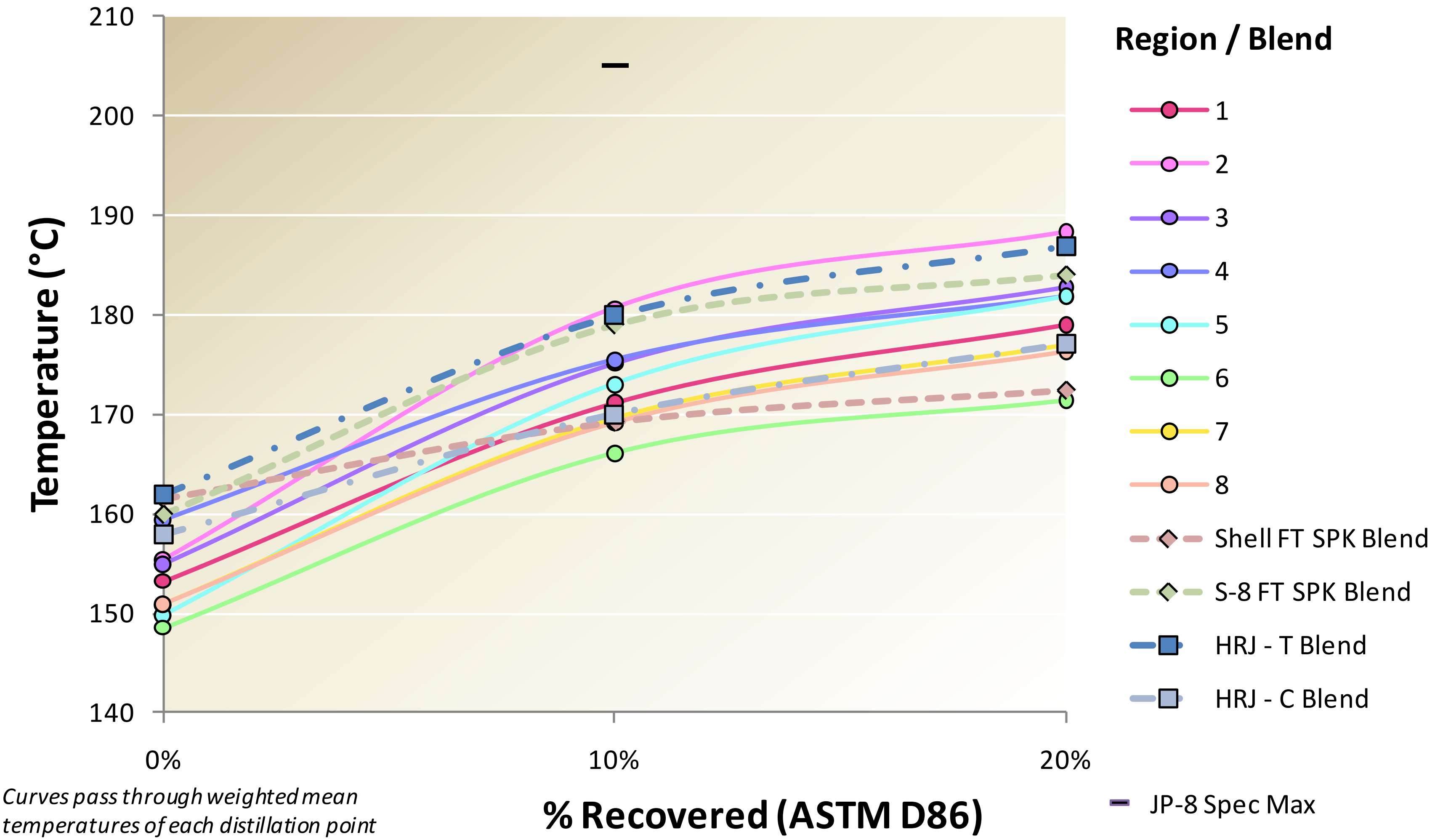


Curves pass through weighted mean temperatures of each distillation point

from PQIS 2008 Annual Report

unclassified

Front-End Distillation: JP-8 Curves vs. Fuel Blends



Curves pass through weighted mean temperatures of each distillation point

from PQIS 2008 Annual Report

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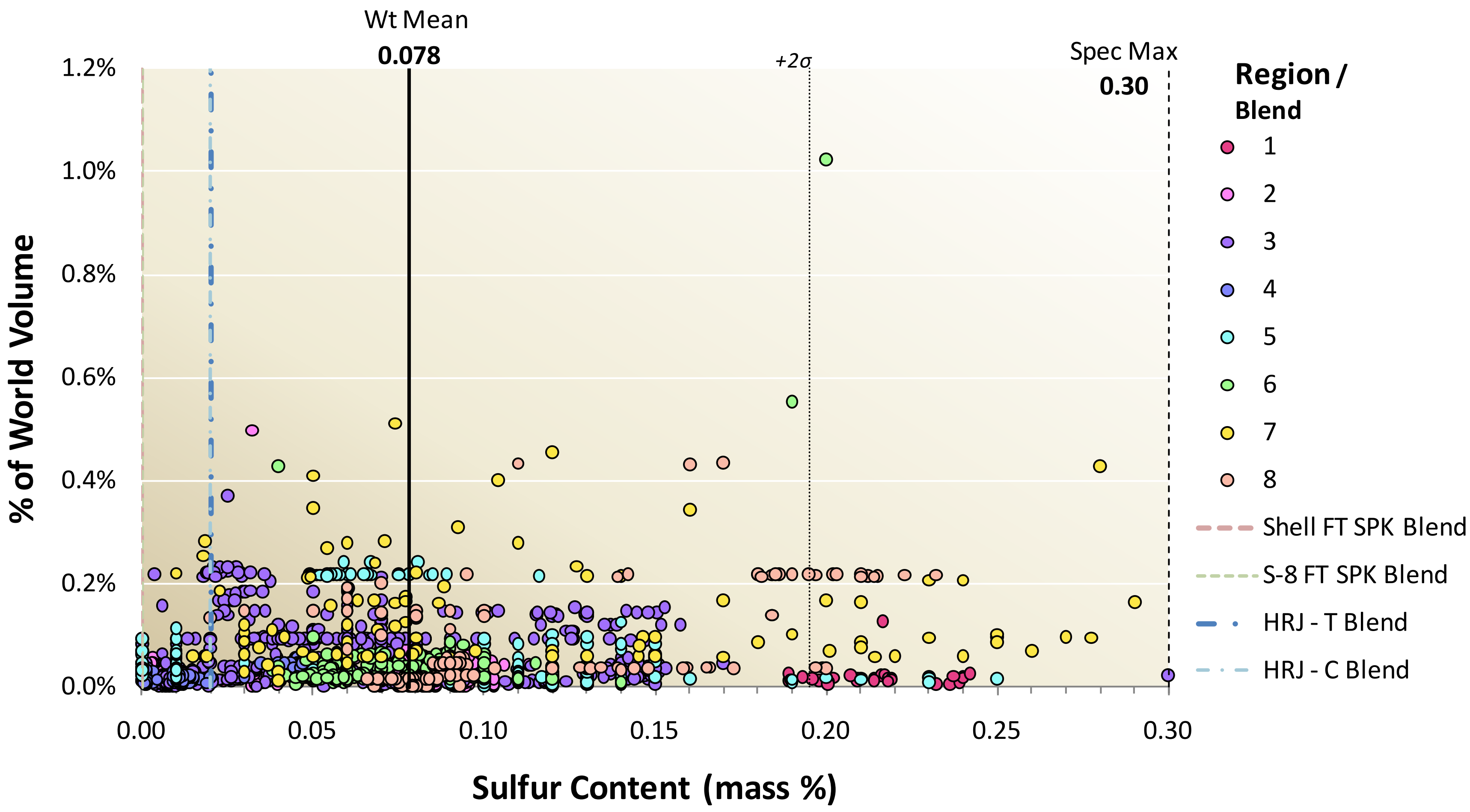
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

RDECOM

Sulfur Content: JP-8 Distribution vs. Fuel Blends

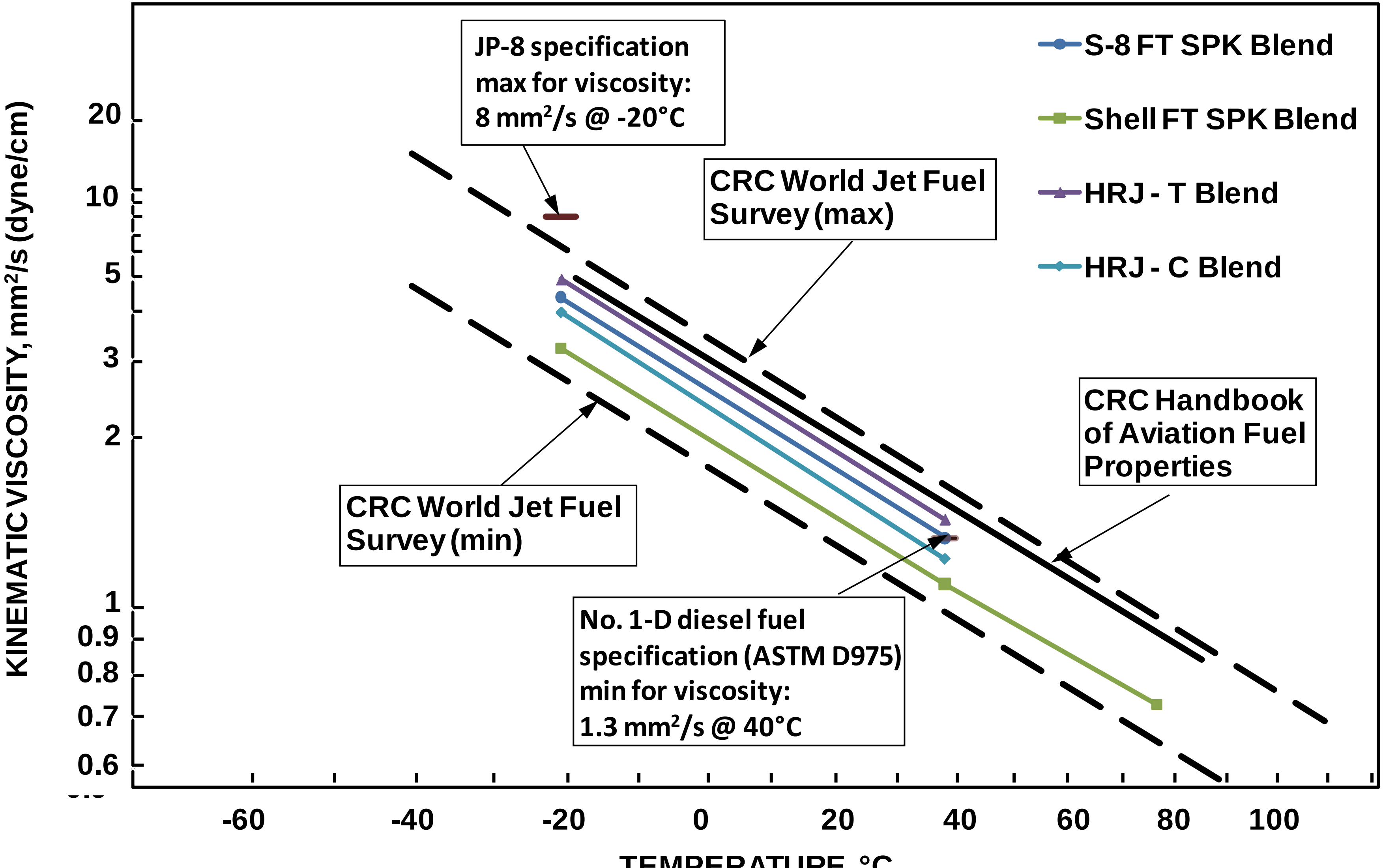
TARDEC



from PQIS 2007 Annual Report

Viscosity: JP-8 CRC Average vs. Fuel Blends

Used with permission from CRC, Executive Director



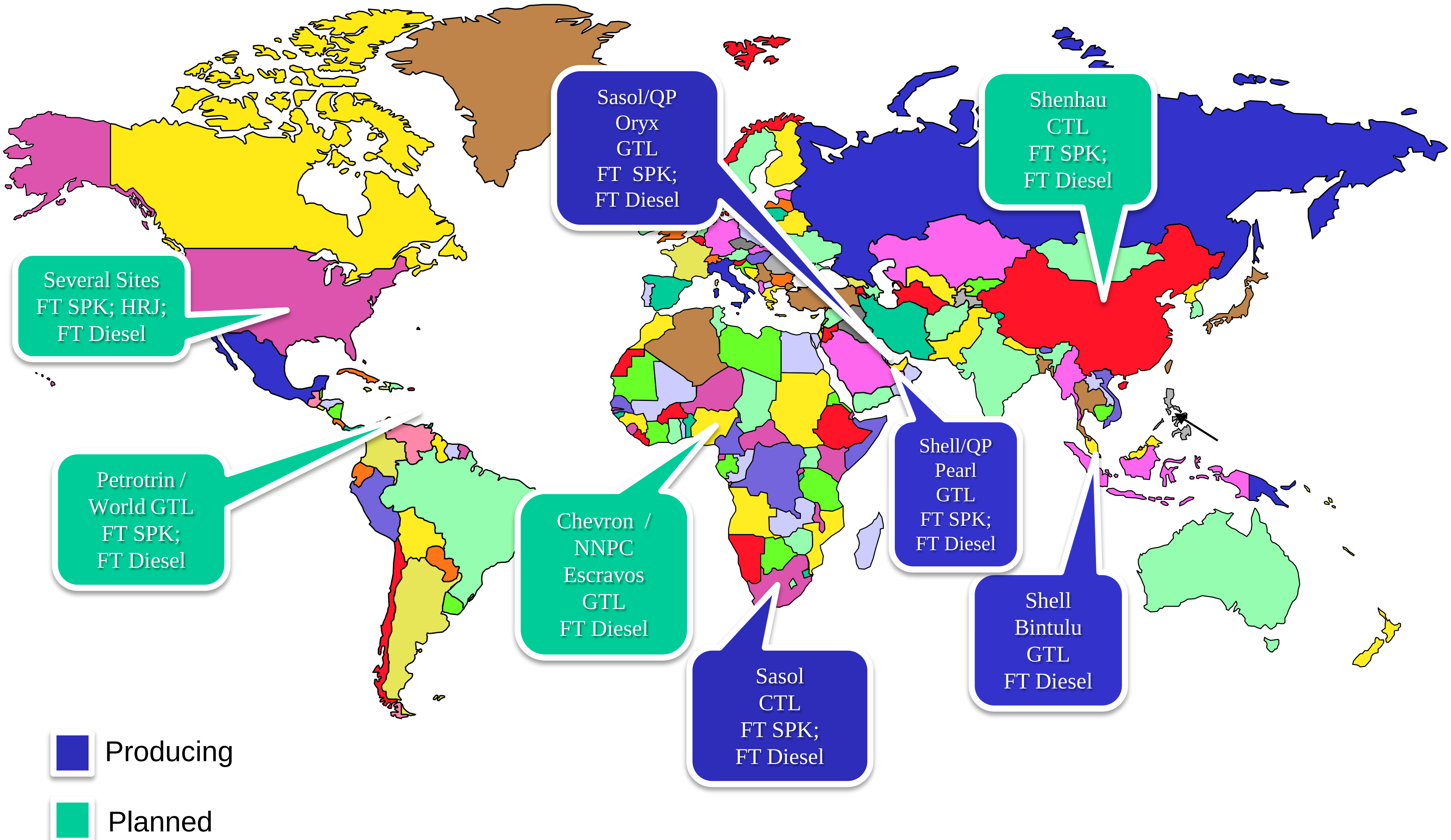
Source: CRC Report No. AV-2-04a

Alternatives to JP-8 – Supply and Demand

- Currently minimal US industrial base for either FT SPK or HRJ but . . .
- There are several ***proposed operational demonstrations for new production facilities*** throughout the US that leverage demand from both the commercial and military (mainly USAF and USN) sectors
  - Hawai'i – GIFTPAC initiative for supply 50% of PACOM tactical fuel with non-fossil sustainable alternative fuel blends from local suppliers
  - Pacific Northwest – 14 airlines signed MOU to purchase output from ***new HRJ facility*** (AltAir Fuels)
  - California – 8 US Airlines agree to purchase output from ***new BTL plant producing FT SPK*** and FT Diesel for use at LAX (Rentech / UOP)
  - Gulf Coast Region – 13 airlines signed MOU to purchase output from ***new FT SPK facility*** (Rentech)
  - Alaska – DLA-E initiative for a ***new FT SPK facility*** on hold pending further DOD decisions

GIFTPAC = Green Initiative for Fuels Transition Pacific
DLA-E = Defense Logistics Agency-Energy

Alternatives to JP-8 – International Supply and Demand



Alternatives to JP-8 – Environmental Compliance

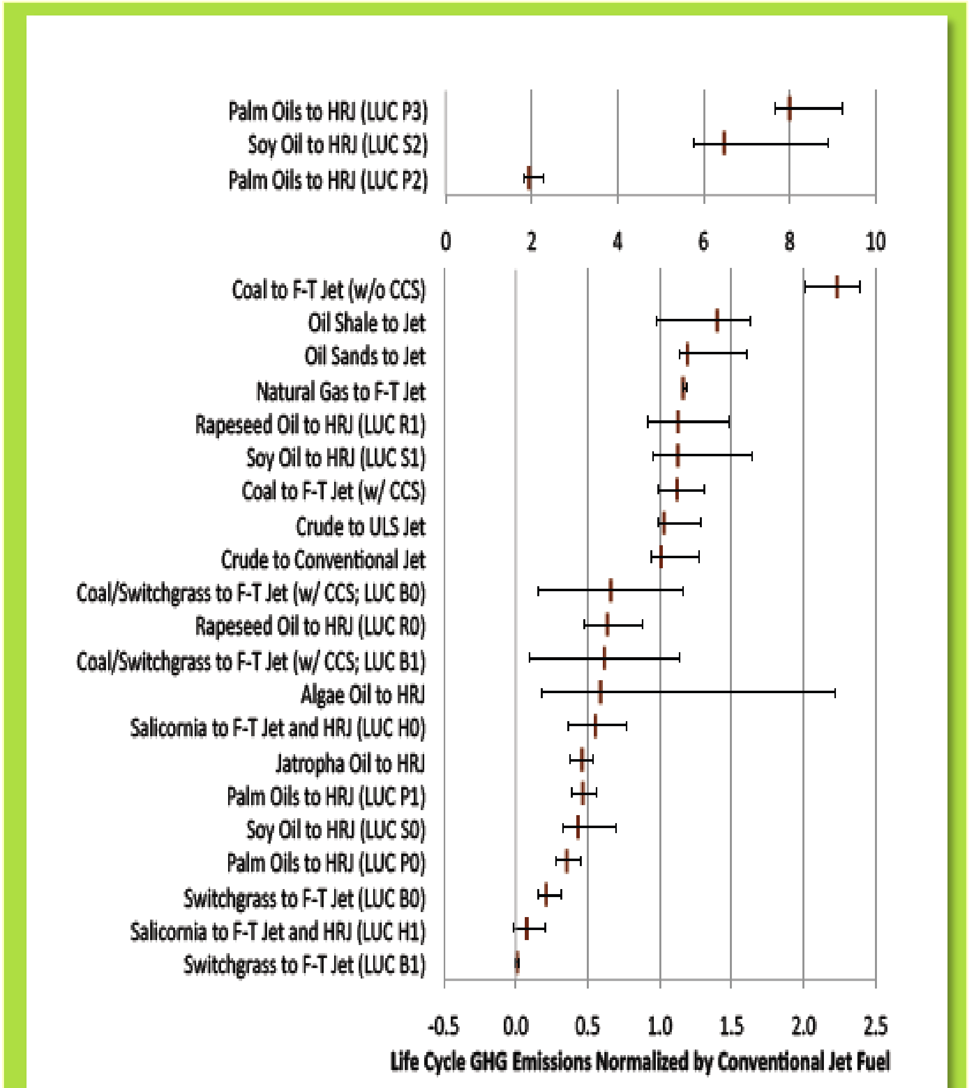
- Per the Energy and Independence Security Act of 2007, Section 526 . . .

  No Federal Agency shall enter into a contract for procurement of an alternative or synthetic fuel for any mobility-related use unless the lifecycle greenhouse gas emissions (LC GHG) of the fuel supplied under contract are no greater than such emissions of the equivalent petroleum-based fuel

- USAF leading a working group comprised of government agencies, academia and industry that is developing framework / guidance of LC GHG emissions of alternative aviation fuels for use in aviation equipment
  - Peer reviewed and released in Dec 2009, “Framework and Guidance for Estimating Greenhouse Gas Footprints of Aviation Fuels”
  - Case studies being conducted per this framework will include language for aviation fuel use (JP-8) in tactical/combat ground equipment
    - “Because complete combustion of the fuel has been assumed, (i.e., all fuel carbon is assumed to be converted to CO_2 via combustion), the life cycle inventory results would be the same whether the fuel were used in a jet aircraft or a diesel engine.”

LC GHG Emissions of Petroleum and Alternative Jet Fuels

- Peer reviewed report of 16 feedstocks-to-jet fuel pathways conducted by PARTNER
  - Screening level study
  - Taken into account were various land use change (LUC) scenarios for biofuels
  - Examined low, baseline, and high emissions scenarios
- Conventional petroleum has lowest emissions among fossil fuels
- Large variability due to unknowns i.e. production processes, LUC, feedstock growth
- Data from report used as part of USAF led group developing framework for LC GHG emissions of alternative jet fuels



PARTNER Project 28 “Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels” Stratton, Wong & Hileman, June 2010

http://web.mit.edu/aeroastro/reports/proj28/partner-proj28-2010-001.pdf

The process to qualify

RDT&E to Qualify Alternative Ground Fuels

EMERGING
ALTERNATIVE FUELS MARKET

- **DOD**
- **DOE**
- **Industry**
- **Academia**
- **Fuel Producers**
- **Equipment OEMs**
- **Other Government Agencies**
- **Standards Development Organizations**

Market Connection

- Manufacturing technology
- Fuel data, samples
- Market drivers

Poor lubricity fuel may cause increased wear rates in fuel injectors and injection pumps.

Fuel / Component Evaluations

- Chemical composition
- Physical properties
- Component performance / durability

Fuel Qualification

Engine Evaluations

- Fuel ignitability
- Fuel combustion
- Performance / durability

System Evaluations

- Operability
- Performance
- Demonstrations

Fuel with low cetane ratings may cause cold-starting problems, and misfire and combustion instability, esp. for lt-med load operation.

Low fuel viscosity may result in fuel pump internal leakage and associated loss of power.

Approval and acceptability of alternative fuels for use in DOD ground equipment.

Alternative Fuels Qualification Technology Readiness Levels

Only a partial representation of TRL tests and evaluations.

Develop data needed to assess fuel's suitability for use.

Build user knowledge of and confidence in use of fuel.

Laboratory Evaluations

- TRL 1: Basic Fuel Properties
  - Distillation
  - Hydrocarbon Range
  - Density
- TRL 2: JP-8 Fuel Specification Properties
  - Oxidative Stability
  - Cetane Index (Report Only)
- TRL 3: Fit for Purpose
  - Storage Stability
  - Material Compatibility
  - Viscosity vs. Temperature
- TRL 4: Extended Lab Fuel Property Test
  - Dermal Irritation Test
  - Cetane No. / Derived Cetane No.

Component Evaluations

- TRL 5: Component Rig
  - Fuel Injection System Testing (Rotary, Inline, Common Rail, Unit Injectors)
- TRL 6: Engine Testing
  - NATO 400-hr test protocol, modified to desert-like conditions
  - 210-hr TWV test cycle

System Evaluations

- TRL 7: Limited Ground Vehicle/Equipment Demos
  - Vehicle Test Track Evaluation
  - Tactical Gen Set Side-by-Side Operability Evaluation
  - TWV Pilot Field Demo
  - Force Projection Equipment Pilot Field Demo

Qualification Report

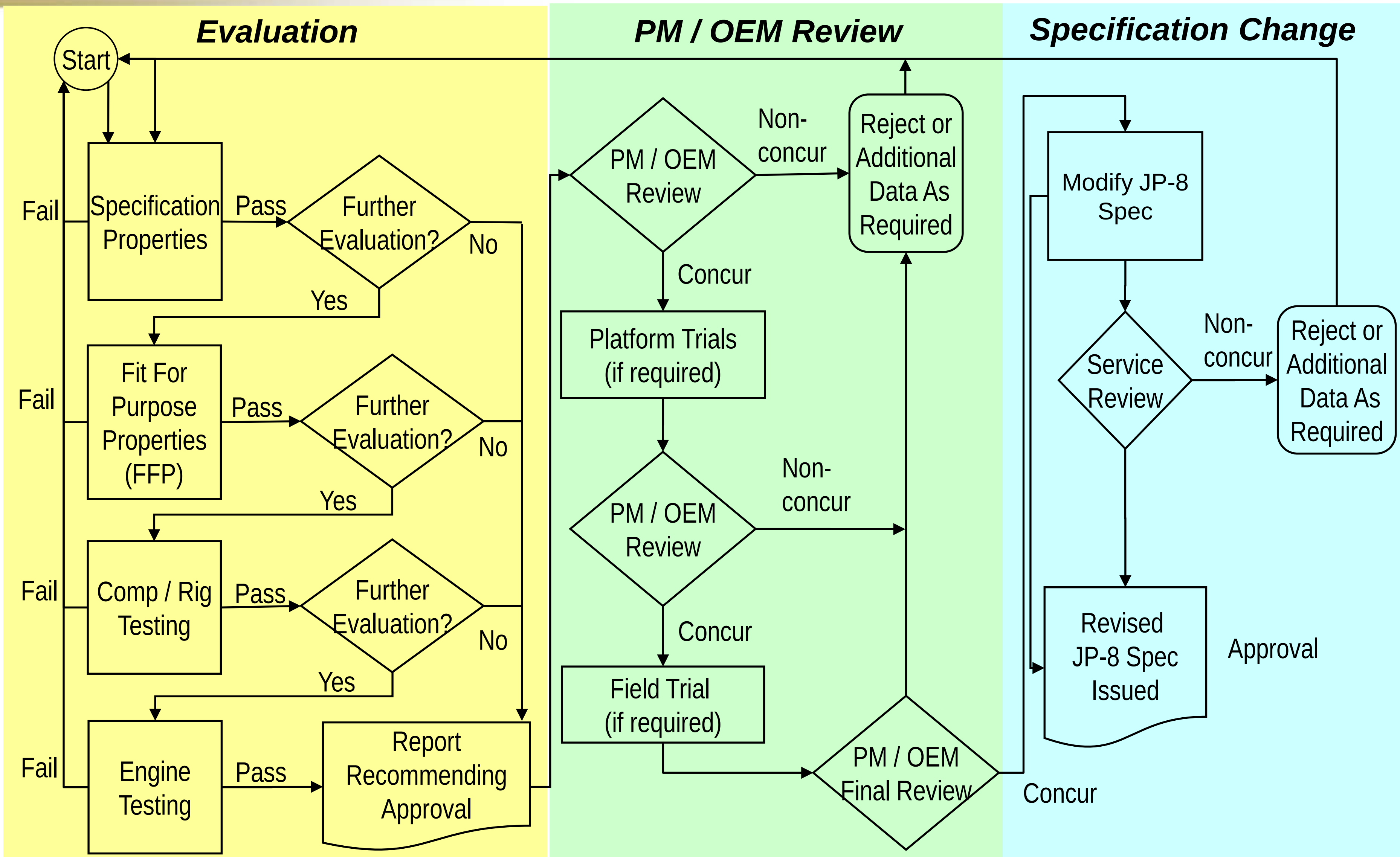
- Executive Summary of RDT&E to PEOs-PMs
- Independent Third Party Review

Demonstrations

AS REQUIRED

- TRL 8: Validation
  - Ground Equipment Evaluations – Proving Grounds
- TRL 9: Field Service Evaluations
  - Ground Equipment Evaluations (typically long duration, at CONUS field locations, wide-in-scope)

Alternative Fuel Qualification and Approval Process



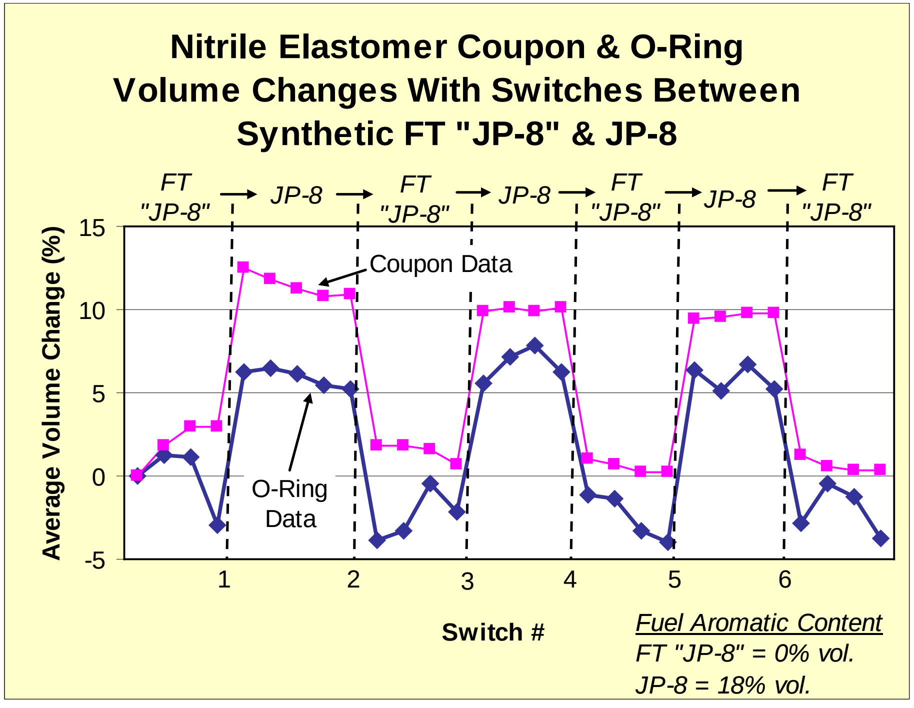
Ref: ASTM D4054-Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives, analogous to USAF MIL-HDBK-510 approach (Jump)

What has been done so far – some examples

TRL 3 – Fuel Blends Are Implementation Path

Completed

- TARDEC elastomer compatibility evaluations supported a blends implementation path*
- Blends of up to 50% by volume FT SPK with JP-8 allowed
  - Blends minimize/eliminate risk of fuel leaks due to change in fuel aromatic content
- Actual FT SPK content possible in a blend, with a given JP-8 batch, may be less than 50 v% since blend properties must meet
  - Minimum density same as for JP-8 fuel (0.775 kg/L)
  - Minimum aromatic content of 8.0 v%



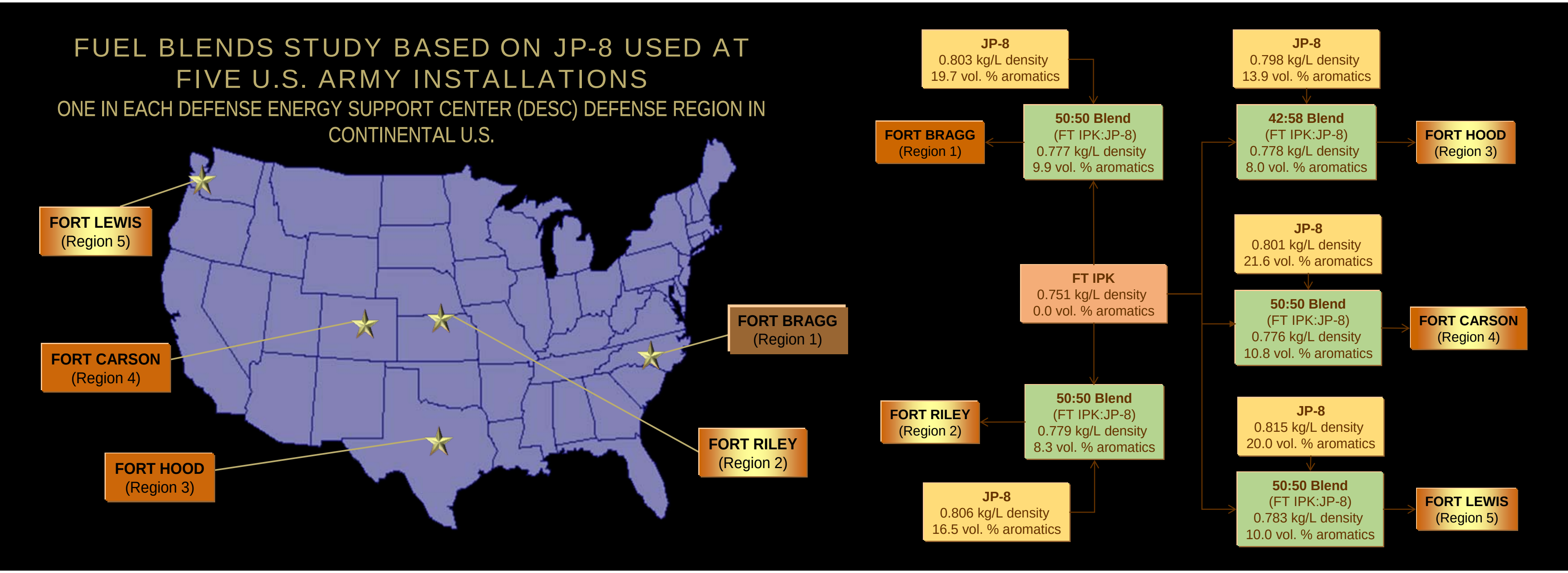
- Nitrile components swell in JP-8, then shrink when switched into FT SPK (FT "JP-8")
- O-ring shrinkage increases risk of sealing failures
- Using unaffected o-ring elastomers or FT SPK in blends with JP-8 are ways to reduce this risk

* SAE Paper 2007-01-1453

TRL 4 – Synthetic Fuel Blends Study

Completed

- FT SPK/JP-8 blend properties*
  - Compared properties of blends with those of typical JP-8 (CONUS, 2004)
  - Properties of blends (up to 50 v% FT SPK) generally fell within JP-8 "property box"
- Follow-on study of typical JP-8 at five Army CONUS installations
  - Maximum FT SPK content possible (50 v%) at four of these installations
  - Only 42 v% FT SPK content possible at fifth installation



* SAE Paper 2006-01-0702

Fuel Injection (FI) Systems

- Why are certain FI systems considered to be high risk?
  - Synthetic fuels are known to have poor lubricity characteristics
    - Because of the lack of certain heteroatoms and trace compounds,
  - Some FI systems rely on the lubricity of the fuel to prevent high wear rates of components and premature failures
    - These components nominally include pumps and fuel injectors
- What about the use of lubricity improver additive (LIA)?
  - ULSD and JP-8 require LIA in order to meet specification requirements for lubricity
  - Synthetic fuel blends will also require LIA to meet specification requirements for lubricity

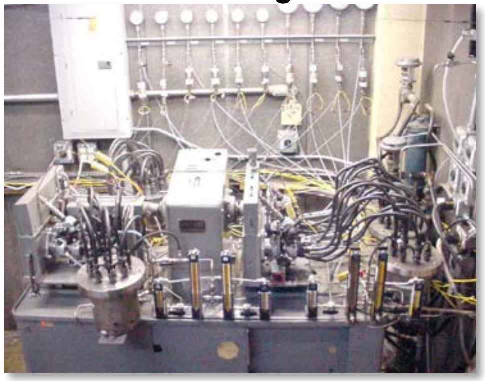
TRL 5 – Fuel System Evaluation: Rotary Fuel Injection Pump

In-progress

- Bench-top lubricity testing
  - ASTM Test Methods: BOCLE, SLBOCLE, and HFRR
  - BOCLE developed for jet fuels, HFRR for diesel fuels
  - FT SPK untreated and treated with military approved lubricity improver additive (CI/LI) per QPL-25107
  - BOCLE results indicate treated FT SPK lubricity is improved, HFRR and SLBOCLE results do not
- Rotary fuel injection pump test rig testing
  - Ambient temperature, 500-hr durability*
    - Untreated FT SPK results showed excessive wear of pump components
    - Treated FT SPK results indicative of acceptable field performance
  - Elevated temperature, 1000-hr durability
    - Baseline fuels (ULSD and Jet A-1), FT SPK, and FT SPK/Jet A-1 blend

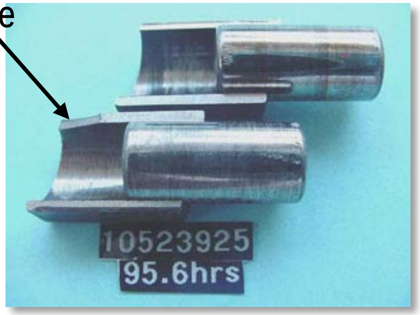
Correlation of results between bench-top and rig tests at ambient T

Rotary fuel injection pump test rig



TARDEC photo by E. Frame,
TARDEC Fuels & Lubricants Research Facility

chipped roller shoe



TARDEC photo by E. Frame,
TARDEC Fuels & Lubricants Research Facility

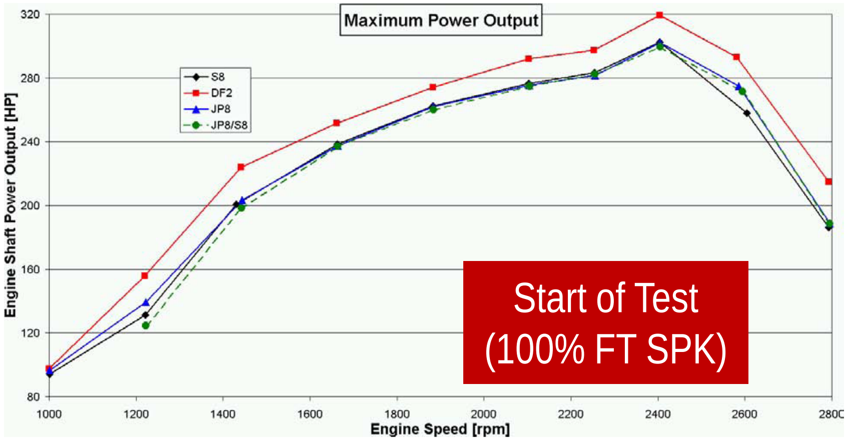
* SAE Paper 2004-01-2961

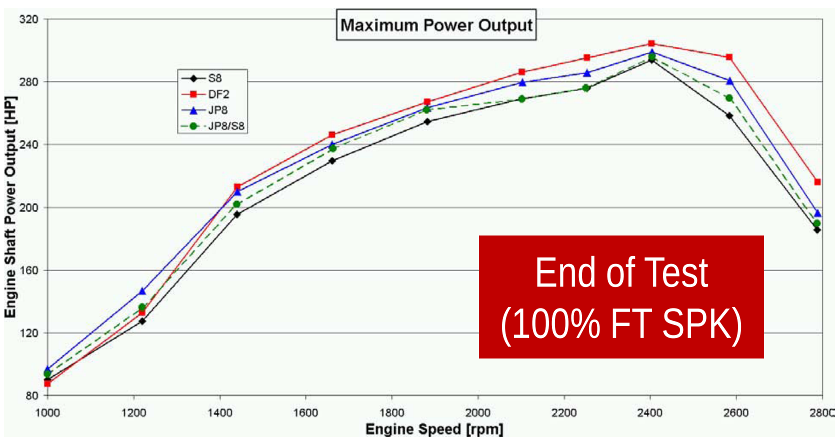
TRL 6 – Tactical/Combat Vehicle Engines: 2 × 210-hr TWV Test Cycle

Completed

- Test protocol (performance and durability)
  - 2 X Army and Coordinating Research Council 210-hr TWV Test Cycle
    - Equivalent to 40,000 miles proving ground operation
    - Two tests: JP-8 and FT SPK (100%)
    - Coolant, oil, fuel and inlet air temperatures elevated to maintain an oil sump temperature of 260°F
- CATERPILLAR C7 engine results (report in DTIC)
  - Power curves for four fuels are all similar, both at start and end of test
    - ULSD
    - JP-8
    - FT SPK (S-8)
    - JP-8/FT SPK blend
  - Post-test engine tear-down found no unusual results for JP-8 or FT SPK
  - Used oil condition similar for JP-8* and FT SPK

Full Load Power Curves



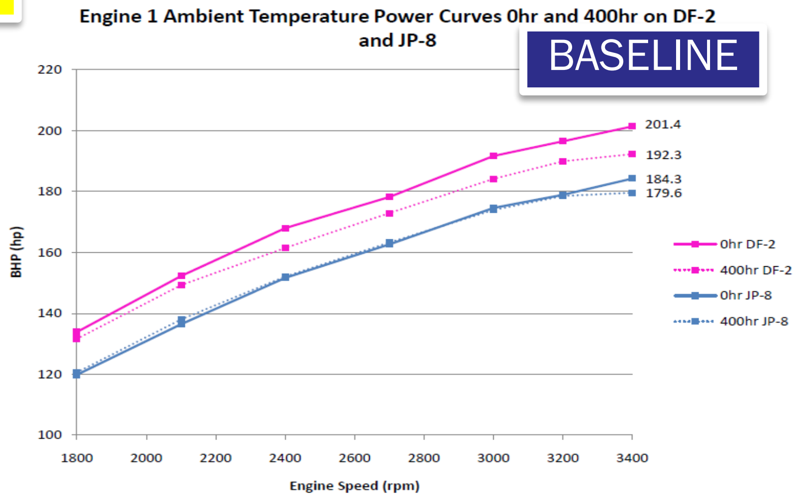


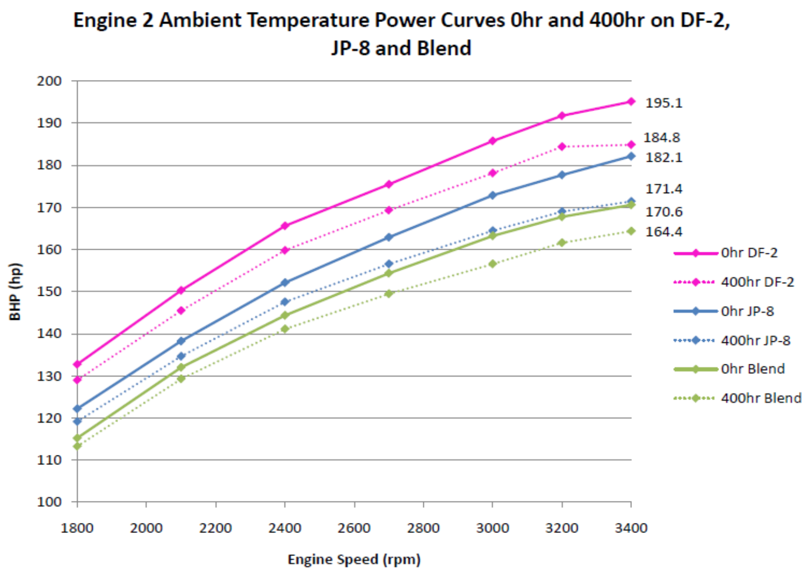
* JP-8 test fuel had low sulfur content of 78 ppm; spec allows up to 3000 ppm sulfur.

TRL 6 – Tactical / Combat Vehicle Engines: GEP 6.5LT Engine 400-hr NATO Testing

In-progress

- HMMWV engine
- JP-8 and JP-8/FT SPK blend (50:50 v%) evaluated under modified NATO duty cycle
  - Testing done at ambient temperature
  - NATO duty cycle modified to accommodate for JP-8 and JP-8/FT SPK blend
- Slight power differences between fuels at ambient conditions
- Pre-/post-test checks of fuel pumps and injector tolerances
  - Performed by manufacturer
  - No fuel related differences observed beyond normal wear
- Additional test using a JP-8/HRJ (50:50 v%) fuel blend





TRL 7 – Tactical Wheeled Vehicle Pilot Field Demo

Completed

- Demo not intended to assess long-term performance or durability of components or engines operating on synthetic fuel blends
- Demo fleet at Ft. Bliss, Aug 08 to Jul 09, operating on FT SPK/JP-8 blend (50:50 v%)
  - ✓ M998 - HMMWV Truck Utility
  - ✓ M915A4 - Line Haul Truck
  - ✓ M925A2 - 5 Ton Truck Cargo
  - ✓ M1075 - 2.5 Ton LMTV Cargo
  - ✓ M1083A1 - 5 Ton MTV Cargo
  - ✓ M1089A1 - FMTV Wrecker
  - ✓ M978/M984 - HEMTT Tanker/Wrecker

This demo served to introduce synthetic fuel blends to the end user and to build acceptance of their use.

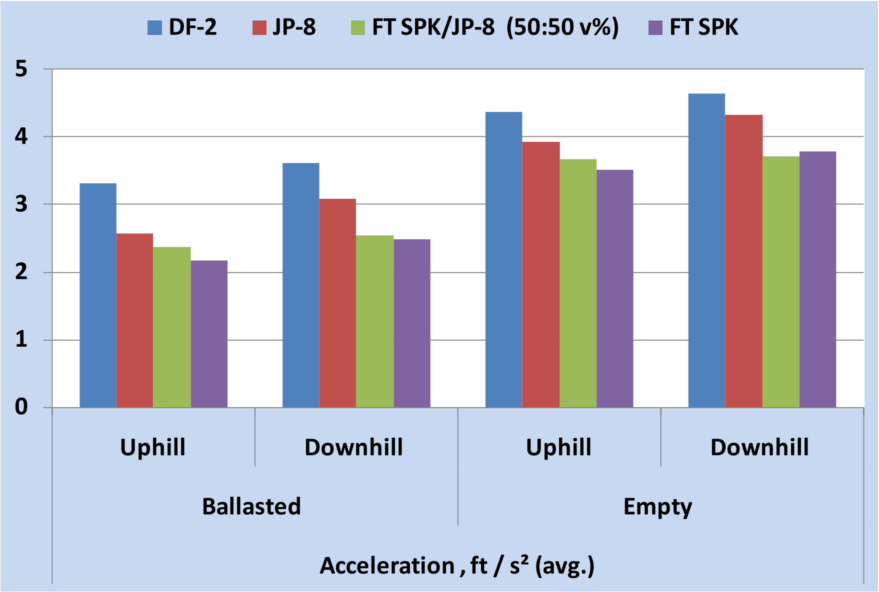
TARDEC photo by R. Alvarez,
TARDEC Fuels & Lubricants Research Facility

- Over 86,000 cumulative miles total
  - > Test vehicles: 47,000 miles and 9,500 gallons of synthetic fuel blend
  - > Control vehicles: 39,000 miles and 6,900 gallons of JP-8
  - > Individual vehicles: A couple operated nearly 5100 miles, many a few hundred miles
- **No issues with vehicle operation throughout demo, no discernible differences to drivers and mechanics between operation of test vehicles versus control vehicles**

TRL 7 – Test Track Performance of HMMWV

Completed

- HMMWV (6.5L N.A.) operated on four test fuels
  - DF-2, JP-8, FT SPK and JP-8/FT SPK blend (50:50 v%)
  - Vehicle instrumented to capture data
- 1000 miles total accumulation
  - On-road and off-road
  - Vehicle acceleration
    - Flat and hills
    - Loaded and unloaded
- Results (report in DTIC)
  - Differences in performance of vehicle in line with expectations based on operating this particular engine/FI system on these fuels and their variation in properties from one to the other



Test results show minimal performance differences between JP-8 and blend; unlikely these will be noticed by driver in the field.

Approval of alternatives to JP-8

Army Requirements and the JP-8 Specification

- **Army conversion from diesel fuel to Single Fuel in the Battlefield (SFB)**
  - Began in 1980's, fully implemented in 1988
  - Army equipment has **generally maintained acceptable levels of performance/durability**, but
- **Some issues; relate to two requirements in diesel spec that are not in JP-8 spec**

1. Cetane No. (minimum of 40, No. 1-D and 2-D)

Cetane no. of fuel is too low → Cold engines take longer to start, or may not start at all! Engines* misfire or combustion is unstable!

2. Viscosity at 40ºC (minimum of 1.3 mm^2/s, No. 1-D)

Viscosity of fuel is too low → Some engines/components do not last as long! Some engines produce less power!

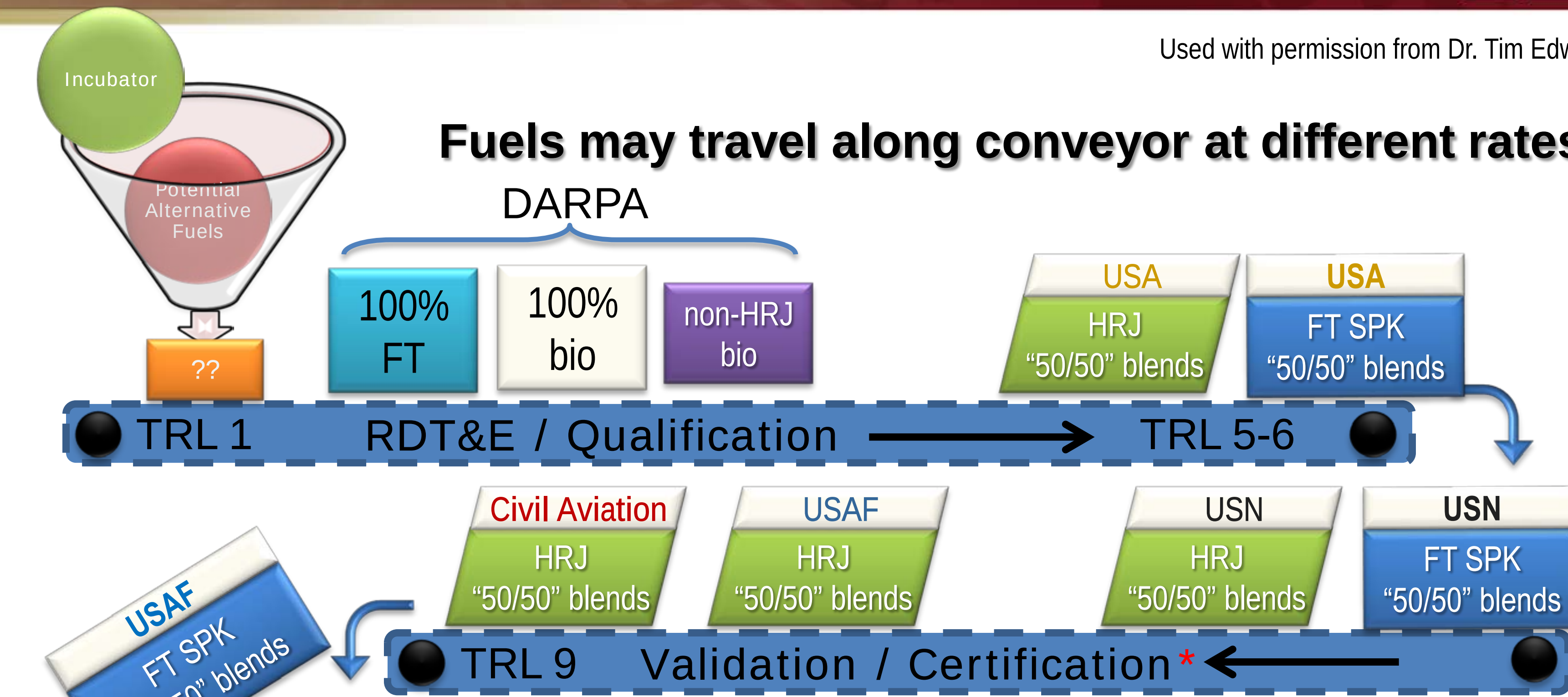
- **For FT SPK (and soon HRJ),** Army wants two requirements added to JP-8 spec:
  1. **Minimum Derived Cetane No. of 50**
  2. **Minimum Viscosity at 40ºC of 1.3 mm^2/s**
- **Current JP-8 spec (REV G) includes notes about desired Army requirements**

*Note: At light to medium load operation

Qualification / Certification Pipeline

Used with permission from Dr. Tim Edwards, AFRL (modified)

Fuels may travel along conveyor at different rates!



*Certification is a term used for airworthiness of aviation platforms, not Army ground equipment

**Approved Fuels, ASTM D7566 - Specification for Aviation Turbine Fuels Containing Synthesized Hydrocarbons

- Issued September 2009
- Criteria for production, distribution, and use of FT jet fuels made from coal, natural gas, or biomass.
- Future versions may allow synthetic jet fuels produced using other processes once they are qualified.

Fischer-Tropsch Synthetic Paraffinic Kerosene (FT SPK)
Hydroprocessed Renewable Jet (HRJ)
Semi-Synthetic Jet Fuel (SSJF)
Fully Synthetic Jet Fuel (FSJF)

Completed TARDEC Evaluations Reports and Papers Available

Document Title	Publication Date	Publication Reference	
		DTIC	Other
Synthetic Fuel Lubricity Evaluations	Sep-03	ADA421822	Interim Report TFLRF No. 367
Synthetic JP-5 Aviation Turbine Fuel Elastomer Compatibility	Nov-03	--	TARDEC Report No. 13978
Exhaust Emissions From a 6.5L Diesel Engine Using Synthetic Fuel and Low-Sulfur Diesel Fuel	Dec-03	ADA426513	Interim Report TFLRF No. 370
Alternative Fuels: Assessment of Fischer-Tropsch Fuel for Military Use in 6.5L Diesel Engine	Jan-04	--	SAE Paper No. 2004-01-2961
Evaluation of Ball on Three Disks as Lubricity Evaluator for CI/LI in Synthetic JP-5	Apr-04	ADA462280	TARDEC Report No. 13977
Synthetic Fischer-Tropsch (FT) JP-5/JP-8 Aviation Turbine Fuel Elastomer Compatibility	Feb-05	ADA477802	TARDEC Report No. 15043
Bench Top Lubricity Evaluator Correlation with Military Rotary Fuel Injection Pump Test Rig	Oct-05	ADA524925	SAE Paper No. 2005-01-3899
Properties of Fischer-Tropsch (FT) Blends for Use in Military Equipment	Apr-06	ADA521910	SAE Paper No. 2006-01-0702
Elastomer Impact When Switch-Loading Synthetic Fuel Blends and Petroleum	Jul-06	ADA459513	TARDEC Report No. 16028
The Effect of Switch-Loading Fuels on Fuel-Wetted Elastomers	Jan-07	ADA497968	SAE Paper No. 2007-01-1453
Evaluation of Synthetic Fuel in Military Tactical Generators	Jun-08	ADA482914	Interim Report TFLRF No. 392
Engine Durability Evaluation Using Synthetic Fuel, Caterpillar C7 Engine	Oct-08	ADA494498	Interim Report TFLRF No. 391
Fischer-Tropsch Synthetic Fuel Evaluations: HMMWV Test Track Evaluation	Sep-09	ADA509165	Interim Report TFLRF No. 400
Evaluation of the Fuel Effects of Synthetic JP-8 Blends on the 6.5L Turbo Diesel V8 from General Engine Products (GEP) 6.5L Engines Using the NATO Standard Engine Laboratory Test AEP-5, Edition 3, May 1988	Dec-09	--	TARDEC Report, Distribution A
Synthetic Fuel Blend Demonstration Program at Fort Bliss, Texas	May-10	ADA533890	Interim Report TFLRF No. 407
Lubricity and Derived Cetane Number Measurements of Jet Fuels, Alternative Fuels and Fuel Blends	Jul-10	ADA529442	Interim Report TFLRF No. 405